① I 29.9/2: C 89/3

②

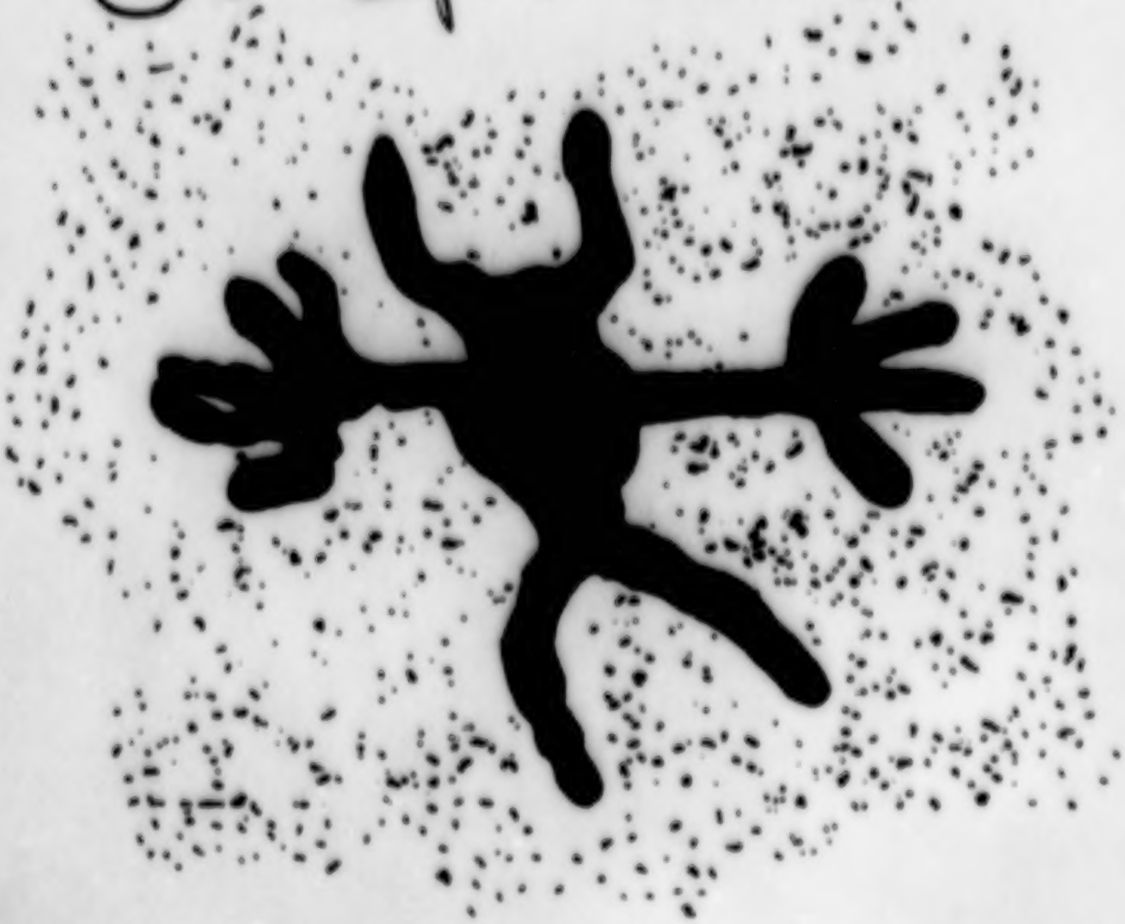
Near-Surface, High Resolution Geophysical Methods for Cultural Resource Management and Archaeological Investigations

0648-A

Don H. Heimmer

Geo-Recovery Systems, Inc.

⑤ U.S. Dept. of Interior



RLP 3-15-94

1992 ⑥

Pub 94-022165
REQ 94-015919

THE ZOO KEEPER

Anthropomorphic petroglyph located on Panel 1,
Rock Art Site 5 LA 5993, Las Animas County, Colorado

(Cover design courtesy of Stephen A. Chomko)

C-0

Near-Surface, High Resolution Geophysical Methods for Cultural Resource Management and Archaeological Investigations

By Don H. Heimmer

Prepared for

Interagency Archeological Services
Rocky Mountain Regional Office
National Park Service
Denver, Colorado

Prepared by

Geo-Recovery Systems, Inc.
400 Corporate Circle, Suite B
Golden, Colorado 80401

Purchase Order No. PX-1242-1-1373

September, 1992

This manual was made possible, in part, with special funding
by the National Park Service through its Cultural Resource Training Initiative.

C-3

ABSTRACT

Archaeological investigations often concern the identification and cataloging of buried historic, as well as, prehistoric structures and artifacts. In most instances, acquisition of this subsurface information is obtained by excavation practices primarily directed by field observation and review of archive records. Recent advances in high resolution, near surface geophysical prospecting techniques and instrumentation, offers the archaeologist a powerful site investigation tool. Detection of geophysical contrasts due to presence of buried materials and human related disturbances can provide an accurate means of locating excavation units. Whereas, the usefulness of geophysical surveying is subject to site specific conditions, a site investigator can determine its site capabilities if a basic knowledge of geophysical methods is acquired.

The purpose of this manual is to provide guidelines for geophysical surveying at archaeological sites; acquaint those responsible for site investigations with applicable surveying techniques and equipment; and present information in relationship to interpretational procedures, quality assurances and reference materials. It is not intended to be the definitive work in theoretical geophysics. It is presented as a translation of techniques developed primarily for mineral exploration that are considered applicable to archaeological prospecting.

PREFACE

Historic, as well as, prehistoric structures and artifacts are often concealed in the subsurface by geologic processes and perhaps more frequently, by human related activities. One aspect of an archaeological investigation concerns the identification and cataloging of these concealed materials. Locating and physical identification heretofore has been performed, in most instances, utilizing information acquired from archival searches, careful visual examination and excavation of the related sites. Nevertheless, removal of culturally barren material is often a time consuming process. Any nondestructive method capable of reducing random excavation practices and increasing the probability of a find should be greeted with great enthusiasm by the archaeological community. One such methodology receiving new or renewed attention is shallow near-surface geophysical techniques. Recent advances in geophysical instrumentation, computer aided interpretational procedures and increased familiarization of cultural resource professionals with geophysical methods gives cause for the writing of this manual.

Geophysical prospecting for culturally related materials is by no means the ultimate panacea for the archaeologist. Geophysical techniques are based on well known physical principles. These principles involve indirect measurements of earth related physical attributes and in the case of archaeological features, contrasts resulting from subsurface disturbances associated with past cultural activities. Where contrasts between the sought after archaeological materials and surrounding soils are small or non-existent the limitations of geophysical techniques and instrumentation become apparent. The actual implementation and success achieved in a geophysical investigation is subject to numerous site specified related conditions. Important factors include; the survey methods, with methods stressed, since it is believed multiple survey methods should be considered a requisite for all site investigations; site compatibility; and the persons conducting the survey must be knowledgeable of selection of proper methods, survey techniques and the nature of results to be expected (i.e., experience factor).

As in any professional discipline, an introductory training manual is normally designed to familiarize, provide basic understanding and reference materials. There are numerous theoretical geophysical references available for those individuals requiring more technical information. Experience indicates there is no preferable learning substitute for an actual participation in a geophysical field survey and subsequent data interpretation process.

Ultimately, the archaeologist often has an enviable role in the archaeological investigation from the geophysicists point of view. The archaeologist has the opportunity to ground truth the geophysical findings and possibly touch our past.

I offer my deepest appreciation to those individuals whom have provided invaluable support and critical review throughout the long and exacting task of preparation of this manuscript. My special thanks to: Dr. B. Bevan, Dr. J. Weymouth, Mr. C. Davenport, Mr. S. De Vore, National Park Service individuals, equipment suppliers and Mrs. K. Heimmer.

Note: Where appropriate, metric system units are utilized to describe geophysical measurements within the text. Due to the fact that some geophysical measurements are customarily described in non-metric units for engineering or mineral exploration purposes, an occasional deviation from this practice occurs.

TABLE OF CONTENTS

PAGE

1.0 Introduction ____ 1

1.1 Historical Background ____ 1

1.2 Remote Sensing Verses Geophysical Methods ____ 3

1.3 Need for High Resolution Geophysical Capabilities ____ 4

2.0 Overview of Near-Surface Geophysical Methods ____ 5

2.1 Passive Geophysical Methods ____ 5
2.1.1 Magnetic Surveying ____ 5
2.1.2 Self-Potential ____ 5
2.1.3 Gravity Surveying ____ 6
2.1.4 Other Passive Measurements ____ 6

2.2 Active Geophysical Methods ____ 6
2.2.1 Active Acoustic or Seismic Methods ____ 6
2.2.2 Electrical and Electromagnetic Methods ____ 7

3.0 Passive Geophysical Techniques ____ 8

3.1 Magnetic Surveying ____ 8
3.1.1 Purpose ____ 8
3.1.2 Limitations ____ 9
3.1.3 Applications ____ 9
3.1.4 Equipment Selection ____ 10
3.1.5 Pre-Survey Site Evaluation ____ 11
3.1.6 On-Site Testing and Equipment Calibration ____ 12
3.1.7 Data Acquisition ____ 13
3.1.8 Field Data Documentation ____ 13
3.1.9 Data Reduction ____ 14
3.1.9.1 Field ____ 14
3.1.9.2 Office ____ 14
3.1.10 Interpretational Processes ____ 14
3.1.11 Presentation of Results ____ 16
3.1.12 Special Considerations ____ 16
3.1.13 Required Expenditures ____ 16

3.2 Self-Potential Methods ____ 17
3.2.1 Purpose ____ 17

TABLE OF CONTENTS (continued)

PAGE

3.2.2 Limitations 17
3.2.3 Applications 17
3.2.4 Equipment Selection 18
3.2.5 Pre-Survey Site Evaluation 18
3.2.6 On-Site Testing and Equipment Calibration 18
3.2.7 Data Acquisition 19
3.2.8 Field Data Documentation 20
3.2.9 Data Reduction 20
    3.2.9.1 Field 20
    3.2.9.2 Office 20
3.2.10 Interpretational Processes 20
3.2.11 Presentation of Results 22
3.2.12 Special Considerations 22
3.2.13 Required Expenditures 22

3.3 Gravitational Methods 22
3.3.1 Informational Discussion 22

4.0 Active or Induced Techniques, General Discussion 25

4.1 Electrical Resistivity 25
4.1.1 Purpose 25
4.1.2 Limitations 26
4.1.3 Applications 26
4.1.4 Equipment Selection 26
4.1.5 Pre-Survey Site Evaluation 27
4.1.6 On-Site Testing and Equipment Calibration 27
4.1.7 Data Acquisition 28
4.1.8 Field Data Documentation 29
4.1.9 Data Reduction 29
    4.1.9.1 Field 29
    4.1.9.2 Office 29
4.1.10 Interpretational Processes 30
4.1.11 Presentation of Results 31
4.1.12 Special Considerations 31
4.1.13 Required Expenditures 31

4.2 Electromagnetic Conductivity Surveying 31
4.2.1 Purpose 31
4.2.2 Limitations 32
4.2.3 Applications 32

TABLE OF CONTENTS (continued)

PAGE

4.2.4 Equipment Selection 33
4.2.5 Pre-Survey Site Evaluation 33
4.2.6 On-Site Testing and Equipment Calibration 34
4.2.7 Data Acquisition 34
4.2.8 Field Data Documentation 35
4.2.9 Data Reduction 35
4.2.9.1 Field and Office 35
4.2.10 Interpretational Processes 36
4.2.11 Presentation of Results 36
4.2.12 Special Considerations 37
4.2.13 Required Expenditures 37

4.3 Ground Penetrating Radar Surveying Methods 37
4.3.1 Purpose 37
4.3.2 Limitations 38
4.3.3 Applications 38
4.3.4 Equipment Selection 38
4.3.5 Pre-Survey Site Evaluation 39
4.3.6 On-Site Testing and Equipment Calibration 39
4.3.7 Data Acquisition 40
4.3.8 Field Data Documentation 41
4.3.9 Data Reduction 41
4.3.10 Interpretational Processes 42
4.3.11 Presentation of Results 42
4.3.12 Special Considerations 42
4.3.13 Required Expenditures 43

4.4 Metal Detectors: Where Do They Fit, Discussion 43
4.4.1 Purpose 43
4.4.2 Limitations 44
4.4.3 Applications 44
4.4.4 Equipment Selection 44
4.4.5 Pre-Survey Site Evaluation 45
4.4.6 On-Site Testing and Equipment Calibration 45
4.4.7 Data Acquisition 45
4.4.8 Field Data Documentation 46
4.4.9 Data Reduction 46
4.4.10 Interpretational Processes 46
4.4.11 Presentation of Results 46
4.4.12 Special Considerations 46
4.4.13 Required Expenditures 46

TABLE OF CONTENTS (continued)

PAGE

5.0 Marine or Submerged Geophysical Considerations 47

6.0 Geophysical Methods Having Limited Archaeological Applications 49

6.1 Acoustic Surveys: Informative Discussion 49
6.1.1 Seismic Reflection and Refraction Methods 49
6.1.2 Shear Wave Seismic Methods 50
6.1.3 Acoustic Emissions 51

6.2 Other Electrical/Electromagnetic Surveying Methods 51

6.3 Borehole and Tomographic Surveying 52

7.0 Quality Control 53

7.1 Purpose 53

7.2 Equipment 53

7.3 Personnel 53

7.4 Field Oversight 53

7.5 Record Requirements 54

8.0 Administrative Requirements 55

8.1 Field Activity Records 55

8.2 Budget Reconciliation 55

8.3 Equipment Usage 55

8.4 Time Allocations 55

9.0 Acquisition Records 56

9.1 Original Data Sets 56

9.2 Data Storage 56

TABLE OF CONTENTS (continued)

PAGE

10.0 Project Planning Requirements 57

10.1 Overall Statement of Project Objectives: Task Definition 57

10.2 Formulation of the Survey Plan: Getting Started 57

11.0 Technical Review 59

12.0 Concluding Remarks: The Perfect Survey 60

Appendix A: Glossary of Terms 61

Appendix B: Selected Bibliography 72

Appendix C: Potential Sources of Geophysical Equipment and Contract Surveyors 87

Appendix D: Geophysical Data Examples and Information Sheets 89

1.0 Introduction

The science of noninvasive identification of subsurface archaeological features is not a new concept. Many nondestructive techniques of site assessments are available to the archaeologist, these include: remote sensing, aerial photography, geochemical testing and geophysics. Since Atkinson's utilization of electrical resistivity in 1946, archaeologists have increasingly employed classical geophysical methods to successfully enhance many cultural resource evaluations (Weymouth, 1986). These methods have included; seismic, gravity, magnetic, electrical resistivity, self-potential, electromagnetic and ground penetrating radar. Recent developments in geophysical related digital electronic technology has increased geophysical site assessment capabilities to aid in cultural resource management.

Improved geophysical instruments and application methods, as well as, computer aided interpretational techniques have allowed, in many instances, study and measurement of earth related physical contrasts with extreme precision. Consequently, minute or small subsurface contrasts attributable to historic, as well as, prehistoric human related activities have a much greater chance of being non-destructively detected utilizing high resolution geophysical techniques.

Introduction or re-establishment of a transfer of knowledge between the geophysical community to the cultural resource management professionals is regarded as a prioritized task. The presentation of information is provided from the view point of engineering/exploration geophysicist rather than limited to that of an archaeogeophysicist or the European equivalent, prospectionist. Geophysical exploration for minerals and petroleum is well known. The application of geophysics to geotechnical engineering, ground water and environmental studies are relatively new developments. Often these noninvasive studies concern characterization of the near-surface materials. Study areas are usually limited in areal extent. The similarity of these studies to a geophysical archaeological assessment is evident. The nature of mineral and petroleum explorations are generally more removed from the archaeological realm due to interest in larger survey areas and greater investigative depths.

The intent of this manual is to familiarize the archaeologist with geophysical techniques considered to be applicable for locating structures, artifacts and defining site limits. The understanding gained will allow the site investigator to realize both the potential, as well as, the limitations of geophysics.

1.1 Historical Background

The separation of geologic and geophysical disciplines is often a difficult task since both are descriptive earth sciences. Geology involves the description of the subsurface by observation of rock specimens or exposed sections. Likewise, the similarity of archaeology to geology is evident since both involve direct observation. In contrast, geophysical techniques are concerned with indirect measurements of the earth's physical properties. These techniques employ instruments specifically designed to detect the influences of subsurface materials. A geophysical survey may be conducted at, above, and below the earth's surface. The nature and contrasts of the observed geophysical measurements may be interpreted to allow a visualization of hidden subsurface geologic structures and compositions.

Within the past 70 years, the increasing sophistication of geophysical exploration techniques are primarily the result of the search for petroleum and minerals, though some advances can be attributed to military purposes. Even into the twentieth century, most mineral exploration was confined to geological means, usually involving some form of direct observation of outcrops or exposures. As much of the easily found, directly observable materials were discovered, new methods of studying the earth's structure or composition were required.

The foundations of geophysical sciences were developed several hundred years ago as the description of the natural sciences progressed. As early as the 1600s, it is reported magnetic compasses were employed to locate ferrous iron deposits in Sweden. Generally, the development of modern geophysical techniques for mining and petroleum exploration began during the period of 1910-1930. In 1913, a sulfide mineral deposit was discovered utilizing electrical resistivity methods. In the 1920's, a technique of seismic refraction, similar to present day earthquake monitoring methods, was developed to locate salt dome structures along the U.S. Gulf Coast. Used in conjunction with the contemporaneously developed torsion bar gravity measurement balance, oil and gas deposits were soon discovered associated with the salt dome features.

Historically, engineering geophysics dates to civil engineering applications in the 1920's. Electrical resistivity and seismic refraction were employed to investigate future dam sites. Measurements of observed contrasts of the velocity of sound within and electrical properties of geologic formations allowed the depth to bedrock and water table to be determined.

Continual progress in improvement of geophysical methods and instrument development has occurred since the 1920's, allowing increasing measurement precision and operational economy. The electronic revolution, as a result of World War II, provided the means to greatly improve geophysical equipment sensitivities and consequently, development of new applications. Development of such methods and instrumentation as radar, sonar, and sensitive magnetometers were quickly assimilated into the geophysical exploration sciences.

Introduction of digital technology brought advances in seismic reflection methods in the late 1960s. Digital stacking of seismic reflection wavelet records allowed enhancement of signal to noise ratios resulting in a better definition of subtle geologic features. This was possible due to the minimization or canceling of seismic related noise during the signal stacking process. Recent techniques in three dimensional and high resolution seismic capabilities have allowed definition of geologic related features with even greater precision.

Development of new electromagnetic instrumentation and interpretational techniques in the 1970s also provided advanced electrical means of describing subsurface geology. Ground penetrating radar, induced polarization methods, magnetotelluric, and various methods of measuring ground conductivity were refined and made available to the exploration geophysicist.

Paralleling the development in geophysical instrumentation, information processing techniques have made enormous gains. Increased geophysical data acquisition capabilities required rapid methods of data reduction for interpretational purposes. Increased computer processing provided a means of enhancing the all important signal to noise ratio of nearly every digitally recordable geophysical data, thereby greatly increasing the interpretive process. Today very few geophysical surveys or interpretational procedures are conducted without the usage of computer technology or analysis.

Though geophysical methods had been adapted to archaeological assessments since the late 1940s, there is not an apparent over abundant usage of geophysical methods to date. Literature indicates most classical geophysical methods have been experimented with to some degree. The use of the proton magnetometer in the early 1950s is often considered the first important application of a geophysical method to an archaeological investigation. Since these early applications of these methods, electrical resistivity, magnetic and more recently electromagnetic and ground penetrating radar have become the mainstay of archaeological geophysics.

1.2 Remote Sensing Verses Geophysical Methods

Clarification of terms is helpful in discussing the application of geophysical methods for archaeological site assessments. As previously stated, there are at least four or more noninvasive methods of site investigations, of which geophysics is one. In layman terms, these methods may be considered as some form of remote sensing, since there is no actual excavation or visual observation performed.

From an engineering or exploration geophysicist point of view, remote sensing is confined to examination of earth features from a distant platform situated above the target area, such as obtained from a high altitude aircraft or satellite. Normally, this type of investigation involves energy bands exploiting the gamma ray - visible light electromagnetic radiation spectrum.

Geophysical methods utilized for mineral or petroleum exploration generally involves examination of large surface areas. Often, particularly in the case of mineral exploration, investigations can be conducted from a rapidly moving aircraft, situated at relatively low altitudes. Surveys that are performed in this manner, do not require coupling of instrumentation with the earth's surface. These surveys include radiometry measurements giving gamma ray distributions associated with radioactive elements, gravity, magnetics and electromagnetics.

Engineering and associated environmental geophysics are more aligned to the classical methods in that they are intrasite assessment methods. For purposes of this manual, classical may be defined as magnetic, gravity, electrical, electromagnetic and seismic methods. Normally, these types of surveys require contact or near contact with the earth's surface. This is required to attain the resolution necessary to characterize the shallow near surface materials. For this manual, thermal differential measurements, aerial photography and geochemical related methods are not considered classical, geophysical exploration methods.

1.3 Need for High Resolution Geophysical Capabilities

Realization of the detail necessary to evaluate an archaeological site dictates the use of high resolution geophysical techniques. As previously discussed, geophysical exploration for minerals or petroleum generally involves evaluation of relatively large areas. The size, nature and distribution of target deposits often create anomalies orders of magnitude larger than those to be expected at an archaeological site.

Evidence of human occupation, in many cases, is represented by materials small in size or relative extent and similar in composition to encapsulating soils. Theory and practical application indicate the sensitivity of the geophysical instruments and methods to evaluate these near surface materials require an ability to measure extremely small contrasts. This necessitates the ability to sample at small, discrete intervals and to measure contrast levels on the order of one part in 100,000. The most applicable methods proved to date that fulfill this criteria include magnetic, electromagnetic and electrical resistivity techniques. Assessments utilizing acoustic (seismic), gravity and variations of electromagnetic techniques have been reported in the literature, and have exhibited limited success on a site specific basis.

2.0 Overview of Near-Surface Geophysical Methods

All materials, whether they be in gas, liquid or solid state, will exhibit characteristic properties. When they are buried in the subsurface, these properties may be lost within or attenuated by the clutter of encapsulating geologic materials, thereby making them indistinguishable from their surroundings. Geophysical methods are concerned with measurements of subsurface physical contrasts. If no contrast exists, geophysical methods are useless and some form of direct exposure of the material must be performed. Since geophysics involves the determination of characteristics of unseen materials it is important that interpreted results be integrated with factual information acquired from other surveys or investigations. Only then can the capabilities and limitations of the geophysical methods be realized.

Subsurface contrasts exist due to mass-density relationships, ionic or electrical potentials, magnetic susceptibilities and elemental decay. Geophysical methods provide a means to actively or passively investigate contrasts in these properties.

2.1 Passive Geophysical Methods

Passive geophysical methods are primarily related to measurements of naturally occurring local or planetary fields created by earth related processes. More distantly related processes of natural elemental decay and thermal interactions may also be passively measured.

2.1.1 Magnetic Surveying

One of the most useful passive measurements to be incorporated in archaeological assessments is magnetometer surveying. The magnetic susceptibility of materials is the basis for this technique. Utilizing sensitive instruments, the earth's total magnetic field can be measured with great precision. Local disturbances or anomalies as compared to the background geomagnetic field can indicate the position of buried ferrous objects, displaced soil materials and earthen structures. Interferences due to more recent cultural activities, geologic conditions and other natural phenomena are the cause of erroneous results.

2.1.2 Self-Potential

Passive, self-potential (SP) methods provide a means of measuring electrical anomalies created by the flowage of fluids, heat and ions in the earth. SP has been utilized in mineral and geothermal exploration, as well as, engineering and environmental applications. Survey attributes are similar to resistivity surveying with the exception that no active electrical current is introduced into the ground. Employing an inexpensive voltmeter and surface contact electrodes, small electrical currents, generated as a result of groundwater flowage, may be detectable across an archaeological site. The differential groundwater movement may cause positive or negative electrical anomalies to occur in areas of buried structures.

2.1.3 Gravity Surveying

Measurement of the earth's gravitational field with accurate precision is also possible. It has been utilized quantitatively and qualitatively to map subsurface geology based on localized and regional rock density variations. Its usage in archaeology is limited due to lack of extreme instrument sensitivity necessary to measure small density variations resulting from sought after cultural features.

2.1.4 Other Passive Measurements

Determination of the concentration of the three naturally occurring radioactive elements in the earth is referred to as radiometry. Radiometric measurements are normally acquired over large areas by airborne survey instrumentation in the search for radioactive minerals. This technique is often relegated to the geochemical investigative area due to the nature of its more chemical qualitative measurements.

Differential thermal analysis, pertaining to archaeology, can be described as a method of distinguishing subsurface features by observation of soil temperature changes over a period of time. A practical surveying technique, as described by Benner, 1984, involves scanning the site area with an infrared camera linked to a computer during the first hours after sunset. Site specific factors such as; soil diffusivity; moisture content; object diffusivity related to its size and depth; solar intensity and frequency; and heat transfer coefficients determine the effectiveness of the technique. This technique is similar to infrared aerial photography. The ambiguities caused by similar thermal properties of many soil type materials can cause interpretational problems. For the purposes of this manual, thermal analysis is not considered a conventional geophysical exploration method.

2.2 Active Geophysical Methods

Active methods involve the transmission of an electrical, electromagnetic or acoustic signal into the subsurface. The interaction of these signals with subsurface materials produces an altered return signal which is measured by the appropriate geophysical instruments.

2.2.1 Active Acoustic Methods

Acoustic methods, seismic, sonar, acoustic emissions or soundings, are based on density contrasts. This method involves the introduction of sound energy into the earth. Measurement of the time it takes the signal to travel from the acoustic source to a listening device, called a geophone, implanted in the ground or submerged in water, allows a calculation of subsurface velocities. Interpretation of the resultant velocities allows for inferences of geologic rock compositions and subsurface structure. Seismic methods include seismic reflection; a method of reflecting acoustic energy from deep subsurface interfaces, seismic refraction; usually a shallow method of determining bedrock depths and acoustic sounding; sometimes known in the archaeological field as bosing. This form of seismic involves introduction of high frequency sound energy into the subsurface or a structure for identification of voids. It is similar to nondestructive testing methods utilized in civil engineering studies. Due to the long wavelength of seismic signals required to penetrate the subsurface, object definition or resolution is poor. Therefore, these methods have found very limited use in archaeology.

2.2.2 Active Electrical and Electromagnetic Methods

Ground penetrating radar, often referred to as GPR, is an electromagnetic method, similar to seismic methods in the sense it exhibits a similar wave form and provides subsurface velocity information. Here the analogy, with the exception of resultant signal display, stops. Operating at high electromagnetic frequencies, radar energy is absorbed or reflected by subsurface materials primarily dependent upon their electrical properties. Resultant velocities can be calculated for depth determination as well as delineation of lateral changes. Radar is a powerful subsurface tool for the archaeologist. Its main pitfall is the lack of penetration in certain clay materials and other highly conductive materials. As with any other geophysical method, it is site specific.

Electrical resistivity surveying is reported to be the first active ground contact geophysical method utilized in an archaeological assessment. It is primarily dependent upon differential electrical resistance related to water saturations in the subsurface. The technique measures the ease which an imparted electrical current will flow through the subsurface materials. Observed lateral and vertical contrasts in measurements can indicate human related structures as well as geologic information. A non-surface contact electromagnetic methodology generally measuring ground conductivity and variations thereof, is similar to resistivity. The difference being that a radio signal is transmitted into the earth in the non-contact method. This signal is altered by interaction with the subsurface materials and detected by a receiver. Since conductivity is the inverse of resistivity, the information acquired is similar to that provided by a resistivity survey. Data can be acquired at a rapid rate since no contact with the surface is required. Many metal detectors operate utilizing the ground conductivity transmitter-receiver arrangement, due to the nature of re-transmission of electromagnetic signals from buried conductive metallic objects.

3.0 Passive Geophysical Techniques

Passive or potential field methods consisting of magnetic and gravity surveying, utilize highly sensitive instruments to measure the effect of a buried feature upon their respective naturally occurring, planetary fields. The magnetometer and gravimeter are capable of measuring perturbations or anomalies due to these features with accuracies of one part in 100,000. A magnetometer provides a measurement of the earth's total magnetic field, in a unit termed gamma or nanotesla (nT). A gravimeter measures the acceleration of gravity or attraction due to mass/density relationships of subsurface features. The basic units of measurement are termed milligals (mg).

Magnetic or magnetometer surveying is very useful for detecting buried ferrous metallic objects or magnetic contrasts of soils. Its usefulness in archaeological investigations is well documented. In contrast, the anomalies produced by an archaeological feature on the gravitational field are minor compared to components related to geologic sources. Though gravity methods have been experimented with for archaeological purposes, such as void detection, its usage is very limited. Instrument and data reduction improvements may lead to applications of this method to archaeological assessments in the future.

The self-potential method, a form of resistivity measurement, has been utilized with limited success in archaeological investigations. Due to certain site specific requirements it is not always a useful method. Resistivity surveying, a similar active technique, is often a preferred replacement for SP.

3.1 Magnetic Surveying

3.1.1 Purpose

Magnetic surveying may be used to increase the efficiency and effectiveness of archaeological assessments by measuring anomalous conditions within the earth's total magnetic field. Spatial integration of acquired data over relatively large areas, as compared to target size, offers superior information to that of point data provided by trenching. Acquisition of data is relatively easy, cost to benefit is excellent and simple qualitative interpretations can be rapidly performed with little experience.

The earth's magnetic field, having a magnetic field shape similar to that of a bar magnet is often referred to as the geomagnetic field. A field intensity change of over 100 percent (100%) magnitude may be observed over the surface of the earth. It ranges from 70,000 gamma (also known as a nanotesla (nT) at the polar regions to 25,000 gamma at the equator. The field is shifted some 11 degrees from the earth's rotation resulting in a deviation from true north. Within the U.S., a 60-75 degree inclination is observed due to the fields origination in the earth's outer core. Where local variations in magnetic materials occur, perturbations or anomalies of less than one to 5000 gamma may be observable.

In theory, the magnitude of the magnetic field strength is a potential field described as a function of a change in energy. Detection of observable contrasts due to the presence of an anomaly are a function of the objects magnetic susceptibility; remanent magnetization; unit volume; and distance between the feature and point of measurement. Magnetic susceptibility is the ease with which a substance is magnetized or induced by the earth's field. Remanent magnetization is the natural or permanent magnetization displayed by a rock or object due to its composition and thermal or depositional history.

Comparison of the response of a theoretically homogenous earth with the observed anomalous value provides a means of detection. Disruption of soils by man, as well as, burial of objects will produce significant contrasts capable of being measured by a magnetometer.

3.1.2 Limitations

Many archaeological targets provide relatively small observable contrasts in the subsurface. Magnetic "noise" due to recent cultural activities, certain geologic conditions and solar activity can, at times, obscure these sought after contrasts. Thus, the operational restrictions that must be considered include both static and moving noise sources, such as:

Recent cultural activities: a.c. electrical power, underground or above ground structures particularly fences within 30 feet (9.14 meters) of the site, water pipes 15-30 feet (4.57-9.14 meters), other utilities, automobiles 30 feet (9.14 meters), signs, and surface, as well as, subsurface trash.

Geologic conditions: rocks and soils having high magnetic susceptibilities or remanent magnetism. Igneous and metamorphic rocks contain relatively high volumes of the mineral magnetite. Soils derived from them may have concentrated amounts. Highly organic soils produce maghemite, the magnetic form of the mineral hematite.

Solar activity: solar wind and solar magnetic storms can greatly affect results. Diurnal changes or daily solar activity can produce 100 gamma changes during a day's surveying. Solar magnetic storms can disrupt surveying for days, resulting in useless data. Utilization of data acquired from a magnetometer base station is often an effective means of filtering or removing unwanted magnetic interferences.

3.1.3 Applications

Performance of a magnetometer survey requires a definition of the archaeological problem. To begin, development of an analog situation, acquired from literature, maybe considered helpful to define these parameters. Knowledge of anticipated target contrasts, though they will be site dependent, generally provide guidelines for survey applications. Upon determination of anticipated contrasts, analysis of the magnetic "noise" must be considered. Noise is related to recent cultural activities, geologic conditions and solar activity. Since high noise levels can obscure measurements of interest, a preliminary field observation may be required to determine whether the survey is possible. If the survey is considered feasible, normal progression of survey design, data acquisitions and associated analyses can be conducted.

Literature indicates magnetic surveying applications for archaeological purposes have included detection of structural features, soil disturbances and magnetic metallic objects.

3.1.4 Equipment Selection

The measurement of magnetic intensities can be performed with three types of magnetometers. Various methods of relating an energy change within the instruments due to the total geomagnetic field are accomplished.

The proton-precession magnetometer is a most commonly employed magnetometer for surveying. Many instruments are capable of measuring the absolute total intensity of the total magnetic field (TMF) to a 0.1 gamma precision. Measurement of the field intensity is performed by induction of a magnetic field on a hydrocarbon liquid contained in a sensor head bottle. The protons of the liquid are displaced from their natural orientation caused by the earth generated field, the so called earth induced field. Upon termination of the artificial field, the protons return to their original orientation at a precessional frequency related to the earth's field, consequently generating a measurable electrical current. The proton magnetometer exhibits two disadvantages. Erroneous observations may occur where gradients of 300-1000 gamma are encountered. These malfunctions can occur due to a.c. power or the presence of iron objects. Also, due to a finite measurement period of time, approximately three seconds, continuous measurements can not be achieved as in the fluxgate or alkali-vapor magnetometer. The proton precession magnetometer is the most commonly used due mainly to its low purchase price, ease of use and precision.

Fluxgate magnetometers are capable of continuously measuring the relative changes in the earth's field. It requires orientation with the earth's field. Due to this requirement, it allows the vertical and horizontal magnetic field components to be measured. Normal sensitivities of 1.0-0.2 gamma are observable with the instruments. Total magnetic field measurements are achieved by measurement of the summation of cyclical coil magnetization of ferro magnetic elements. The outputs produced are proportional to the total field. The primary disadvantage of this instrument is the orientation requirement, though directional capabilities may be useful, depending upon survey requirements.

The cesium or alkali-vapor lamp magnetometer is the most sensitive of all magnetometers (0.01 g). Like the fluxgate, in non-multi cell instruments, it requires both a non-parallel and non-perpendicular orientation to the earth's field. It utilizes an optical beam system of light excitation where a radio frequency measurement of vapor opacity verses transparency allows for magnetic field determination.

The measurement of the magnetic field utilizing two magnetic sensors mounted in a vertical mode is known as gradiometer surveying. Gradiometer surveying allows for minimization of strong gradient influences and solar or diurnal effects, greater resolution of features and in some instances, clarification of magnetic anomalies with greater precision. Since the sensor's are separated by a small fixed distance, approximately 2.5 feet (0.75 m), they measure the earth's field with similar results. Due to the distance dependence of the sensor to anomaly ($1/r^3$), subtraction of measurements between sensors will define near surface anomalies with increased resolution. Both methods, gradiometer and total field, have their advantages and disadvantages and are partially complementary. The selection of method is dependent upon site requirements and operator preference.

3.1.5 Pre-Survey Site Evaluation

Due to the limitations of magnetic surveying, a site evaluation is recommended prior to the data acquisition phase. It is assumed a basic knowledge of the site geology and archaeological content is available for evaluation purposes. Upon analysis, site compatibility with magnetic surveying is established. Usage of recent aerial photography is highly recommended to expedite survey design. The following pre-survey activities are recommended:

- Identify sources of magnetic noise interference, adjust grid lines and stations to minimize effects.
- Determine line and station intervals to maximize site coverage, providing for anticipated anomaly size.
- Design program to intersect observable features of interest, since these features will undoubtedly be of interest to the site investigators.
- If previous assessments, such as trenching or other geophysical surveys, have been conducted be sure to include these areas within the magnetic survey for data correlation purposes.
- Remoteness of the site will affect equipment and survey requirements. Provide for in the field computer analysis for data inspection purposes when possible.
- Select magnetometer equipment, either gradiometer or total field, to match the job. If a large survey is to be performed, arrangement for additional magnetometers is highly recommended for both surveying and base station diurnal measurements.

- Provide for suitable non-magnetic surface locating markers.

- Arrange for surveyors to mark baselines and stations before beginning the acquisition phase. The survey can be performed at an extremely rapid rate in the range of 2200 measurements per day. If the geophysical crew is expected to perform this function, survey speed will diminish accordingly.

- Provide for line locating on base maps for anomaly definition.

- Schedule other assessment activities before or after the survey, as the presence of equipment nearby could possibly appear as magnetic noise.

- Be prepared to modify or adjust survey parameters upon initial data or site analysis.

3.1.6 On-Site Compatibility Testing and Equipment Calibration

On site instrument and operator checks are required to assure that a high quality survey is performed. Calibration of the magnetometers consists of "tuning" or adjusting the sensitivity with relationship to the geomagnetic field at the site. This figure corresponds to the field strengths of approximately 50,000-60,000 gamma across the United States. Tuning is preferably conducted in an area free of magnetic disturbances whenever possible. Likewise, if a second magnetometer is utilized for a base station to measure diurnal or temporal effects it must be compatibly tuned with the moving survey instrument. If a base station instrument is not available, a base station location can be established where the one survey instrument is taken throughout the survey day to acquire diurnal correction information. If a gradiometer is utilized for the survey, a diurnal check is not necessarily required, but is recommended as a daily check of equipment operation.

Upon or prior to instrument tuning, instrument function checks are required: batteries are charged, magnetometer memory is clear of extraneous readings, the magnetic sensor is orientated properly with respect to the geomagnetic field and the sensor is placed on the survey staff at an applicable height above the surface to detect contrasts of interest. The staff height selection may be adjusted after acquiring a test line. It should be remembered the greater the distance between the sensor head and the anomaly, the less influence the anomaly will have on the magnetic field intensity. Also of vital concern, the operator must be relatively free of magnetic materials if data contrasts of 1 gamma or less are to be observed. It must be remembered the localized field created by a magnetic source is defined the distance relationship of $1/r^3$.

The acquisition of a test line over a known feature is highly recommended, if possible. This provides an opportunity to observe site specific characteristics. Survey parameter adjustments can be performed upon analysis of this information. In the rare instance, this information may reveal some unforeseen site characteristic or the occurrence of a solar magnetic storm that may preclude the performance of the survey. Normally, successive readings taken at each location should not vary more the + or - 1.0 gamma if they are to be considered valid.

3.1.7 Data Acquisition

Upon establishment of a survey grid, data acquisition consists of progressing down the survey line and obtaining measurements at each station interval. Observation of several successive readings taken at each location determines the validity of the measurement. In areas of strong gradients, valid measurements may be impossible to acquire and should be noted. The time spent trying to obtain a valid reading can increase surveying time considerably. Generally, if only one instrument is utilized for measuring the total magnetic field, a measurement must be taken at a pre-selected base or fixed location for diurnal corrections before the start of each profile line or at selected time intervals.

Modern magnetometers are capable of being programmed to store in memory a line and station sequence as well as the time of day for each measurement taken. Depending on site and survey requirements, a surveyor can acquire an average of 2200 measurements on a good day. Magnetometer memory storage capabilities, before a transfer of data readings are required to the computer, are instrument dependent. The least expensive models will record 1200 data location points while more expensive model instruments can record up to 12,000 locations.

Experience and knowledge of the equipment operator is an important factor in a survey. Equipment malfunctions, data quality and visualization of anomalies can, in most instances, be quickly assessed by the experienced operator. This ability provides a quality assurance ultimately affecting the effectiveness and rate of surveying.

Often the boredom and fatigue of acquiring magnetic data affects even the most conscientious operator. Therefore, it is recommended, at least for larger surveys, a second operator by available. This person can help in data acquisition, provide site support, survey quality control, and perform preliminary data analysis.

3.1.8 Field Data Documentation

Good field notes are necessary to indicate variations in survey parameters such as line locations, station skips, and other general disruptions encountered during surveying. A field book is generally kept with the operator to record these features. although the magnetometer is capable of keeping track of the readings, and in some cases allow input of small messages, the notebook is nearly always referred to during data reduction and analysis.

3.1.9 Data Reduction

3.1.9.1 Field

A daily inspection of the acquired data is often necessary to check quality and direct survey activities. An ability to inspect or analyze the data necessitates a numerical correction to the data to remove the time varying changes in the magnetic field. This can best be accomplished by transferring the data from the magnetometer to a portable computer. Utilizing appropriate computer software often supplied with the magnetometer, an average gamma value correction per time interval, determined from simultaneously acquired base station data, is multiplied by the difference in time between each successive field reading. The result of each calculation is processed or subtracted from corresponding field measurements. These values can then be depicted as a magnetic profile where distance along the profile is plotted against magnetic intensity. Review of paralleling adjacent profiles allows for recognition of regional features, and smaller wavelength anomalies. Computer assisted contouring programs are also useful for reviewing acquired data on a daily basis. Interactive features allow for filtering of the contoured data to remove data obscuring interferences.

Instances where remoteness of the site precludes usage of a computer, a manual inspection of data can be performed. Performance of this task is laborious requiring calculation of the correction values and subtraction and plotting of results. Large surveys conducted under these circumstances require usage of magnetometers with extended data storage memories.

3.1.9.2 Office

Data reduction in the office environment is similar to operations conducted in the field, when a computer is available. Office activities often allow a more detailed analysis of the data, perhaps involving applications of refined filtering techniques to produce residual magnetic profiles or magnetic intensity contour maps.

3.1.10 Interpretational Processes

Every site survey produces a unique magnetic intensity data set. Anomaly separation or development, necessary to distinguish features of interest from those created by noise, varies accordingly . In situations where a survey is confined to a small undisturbed area of homogeneous soil containing magnetically monaxonic features, data interpretation may be self evident, dependent upon the investigators experience. Addition of interferences due to noise sources such as fences or building structures, increases complexity. Due to magnetic consequences of complex geology, magnetic target pattern recognition becomes extremely difficult. As a result, interpretation processes can attain nightmarish proportions, often resulting in an insufficient time allocation for the interpretation process.

The signature of an object buried within a homogeneous material can best be described as a bar magnet orientated in various positions. It creates its own magnetic field or disturbance within the geomagnetic field. If it is laid upon its side, it will be observed as a north-south or positive and negative magnetic dipole anomaly. Standing it on end, a monopole, either negative or positive will be detectable. Orientation changes of the bar magnet will often create complex asymmetrical dipole anomaly shapes dependent upon magnetic intensities and the distance to the magnetometer sensor. If anomalies associated with artifacts, soil disturbances or structures overlap as they often do in anthropogenic relationships, contributions generated by each source can create complex anomalies.

Interpretation of the significance of a feature is site specific. Integration of all available site information to determine site context is required. If the site is of historic significance the anomaly intensities will generally be greater than those found on a prehistoric site, all other parameters being equal. Presence of near surface iron objects will create high intensity anomalies. Structural elements may be observable as small broader anomalies exhibiting some sort of lineation, if magnetic susceptibilities and remanent magnetization offer proper contrasts. Surveying performed at prehistoric sites indicate contrasts are often very subtle, requiring close examination by the interpreter. It is a rare occurrence, for example, to identify the signature of the thermo-magnetization associated with the burn site unless contrasts of 1 gamma or less are observable. Modelling is a useful method of visualizing the significance of an anomaly, though the model chosen may not be a unique solution. Also, the determination of a background gradient developed from a nearby area unaffected by archaeological materials can be utilized in the model. Removal of this non-anomalous portion of the data can enhance detection of archaeological anomalies through the modeling process.

Appreciation of the diverse types of magnetic anomalies is therefore an interpretive requisite. Most importantly, comparison of survey results with known features are the greatest interpretative aids and part of the experience factor. The following functions are recommended for a site survey:

- Surveying be conducted within a nearby clean area, free of the sought after archaeological features or other magnetic interferences.
- Excavation of several anomalies be conducted to "calibrate" or ground truth the survey data.
- Integrate all available data for discrimination of noise from features of interest.

The extra time and effort expended in performing these functions will greatly enhance the success of the survey.

3.1.11 Presentation of Results

A report of findings, in a narrative format, is generally provided with the magnetic intensity profiles and /or contour map depicting the results of the survey. This narrative normally describes the objective of the survey and goes on to provide information as to how the objectives were met. The following should be presented: survey objective; statement of tasks required to be performed to satisfy the objectives; description of the chosen method and equipment utilized; survey grid delineation and why chosen; other information utilized to be integrated into the results; an interpretation of the findings as related to maps or profiles describing their significance; survey conclusions; recommendations.

3.1.12 Special Considerations

The investigator should be continually aware of possible magnetic noise or interferences generated by both above- and below-ground features. He must also anticipate site circumstances (topography, access, burial depth, etc.) that can affect the outcome of the survey and adjust the survey to fit objectives. During actual surveying the survey grid must be refined enough to provide adequate coverage of the anomaly; the magnetic sensor must be orientated correctly and held very still during measurements.

3.1.13 Required Expenditures

Magnetic survey instruments, particularly a proton precession magnetometer, is a relatively inexpensive piece of equipment compared to other geophysical instruments. Currently an instrument can be purchased for approximately $4500 (1992). A proton magnetometer configured as a gradiometer instrument can be purchased for approximately $10,000 new (1992). Instrument rental costs are approximately $25 per day. Used instruments can occasionally be found considerably less expensive. Fluxgate and alkali vapor equipment are considerably more expensive (purchase price $ 10-20,000, 1992). A contractor field crew of two surveyors, and equipment, will require an approximate expenditure of $800 per day plus per diem. This should include a daily data quality check either provided as magnetic intensity profiles or possibly some type of contoured intensity map. This information should not be considered the final data interpretation. The quoted cost may or may not include the establishment of a grid coordinate system across the site. Depending upon the site assessment, as to necessary locating refinement, survey locating requirements may be considered as an additional expense.

Contractor interpretation expenses can vary according to survey needs. If formal maps and a narrative are required additional time will be required to perform these functions. Generally, a cost of $400 per day (1992) can be expected. Experienced interpreters will allocate two days of office interpretation time for every day spent in the field surveying.

3.2 Self-Potential Methods

3.2.1 Purpose

Small naturally occurring positive or negative electrical potentials, measured in millivolts, are generated by fluid flow, mineralization and geothermal gradients within the earth. Referred to as self-potential or spontaneous potential anomalies, a qualitative interpretation of their relationship to subsurface features can be determined. Generation of a mineralization or background potential requires the formation of a chemical concentration ion exchange cell. When potential electrolytes flow through a porus media, coming into contact with each other or a solid mineralized body, negative and positive electrical potentials having values of ten to several hundred millivolts may be observed. Background potentials may be generated by groundwater flowage through a hydrogeologic capillary system. In the near surface, groundwater flowage collects and transports positive chemical ions through the porous media, concentrating a positive change at the exit point and leaving a net negative charge at the point of entry. If a significant charge differential is developed, location of the seepage points may be identified. For mineral exploration purposes, where fluids are in contact with a solid mineralized body, observations of a negative millivolt anomaly is likely.

A voltage meter reading acquired from two or more porous pot metallic electrodes positioned at selected survey locations provides a means of measuring these electrical potentials.

3.2.2 Limitations

Self-potential methods are subject to numerous site specific, as well as, survey difficulties. A primary requirement, particularly with respect to archaeological surveying, is that a measurable electrical potential must exist within the area and depth of interest. Often, due to the shallow near-surface nature of archaeological investigations, no measurable contrasts may be observed. It must be assumed self-potential anomaly amplitudes generated by archaeological features will in most instances be small. Data quality will be dependent upon acquisition procedures, field data reduction, and recognition of natural, and artificially generated noise. Since data interpretation concerns comparison of source models to observed field data, non-unique solutions exist for all data sets. Additional limitations or data errors involve non-reproducible field observations due to continual changes in shallow soil moisture conditions, electrode polarization drift and time varying earth telluric electrical potentials.

3.2.3 Applications

Self-Potential methods were first utilized in mineral exploration. Their application to engineering and environmental investigations are relatively recent developments. Generally, SP surveying is often used as a cost effective, rapid reconnaissance investigative tool prior to performance of other geophysical studies. Specific applications for engineering and environmental investigations include determination of groundwater flowage and seepage from containment structures; the affect of man-made structures and geologic features on flowage patterns, and delineation of chemical contaminants in the subsurface. Applications for archaeological investigations are generally related to near-surface water flowage patterns associated with buried structures or disturbances. Where flowage is absent, it is likely no self-potential anomaly will be observed.

3.2.4 Equipment Selection

Self-potential measurements can be obtained using a high impedance digital voltmeter, three non-polarized porous pot electrodes and connection wire. Due to the simple nature of the equipment, it generally is not available from geophysical supply sources. Therefore, the required equipment may be acquired on a local basis. Non-polarized electrodes generally consist of copper-copper sulfate or silver-silver sulfate electrodes. They are available commercially through pipeline corrosion survey suppliers. Connecting wires should be insulated, single conductors, of suitable lengths varying from 1000-2000 feet for large survey areas and up to several hundred feet for archaeological investigations.

3.2.5 Pre-Survey Evaluation

It is essential that site specific factors are accounted for or reviewed before a survey is attempted. These generally include:

- Knowledge of soil moisture or ground water flowage conditions at the site. Generally if the soil conditions are dry and archaeological targets are earthen structures, the method has little chance of succeeding.

- Review of geologic features, including topography, mineralization and soil properties to predetermine their affects on a survey.

- Elimination or verification of cultural and other noise sources, such as stray or grounding electrical currents, buried metallic objects and surface waters.

Overall, it must be realized self-potential values associated with archaeological features will be small. Electrical potential variations due to numerous interferences can easily obscure the sought after information.

3.2.6 On-Site Compatibility Testing and Equipment Calibration

Implementation of site specific, reproducible field procedures requires excellent equipment calibration and compatibility testing. Acquisition errors must be minimized for low amplitude anomaly recognition.

Equipment system checks involve determining if the voltmeter is operating properly and calibrating the porous pot electrodes within a known metal salt solution bath. Normally, a third electrode is left within the salt solution bath as a reference electrode for comparison with the field measurement electrodes. As the field electrodes are moved about and placed in the soil, electrode polarization and drift occurs. Elimination of these errors may be achieved by periodic reference to the salt bath solution electrode.

A survey base station, selected in a relatively quiet area of the survey site, should be established. This site may be designated as the zero potential point site, since SP measurements never have a real universal zero potential reference level. This site is to be periodically returned to during surveying activities to provide background values and as a test location for data reproducibility. Measurements acquired at this location allow corrections to be made for noise related to: changing soil conditions, temperature, temporal telluric potentials, as well as, other natural and artificial sources.

3.2.7 Data Acquisition

As in all potential field surveying, SP survey design is dependent upon anticipated anomaly size. Since archaeological features are generally small in size and near surface, close measurement station spacing is required. Station spacings on the order of five to ten feet, acquired along parallel lines five to ten feet apart is recommended as a general rule. Loop closure or tie point reoccupation of measurement stations is also recommended to provide quality control for measurement reproducibility.

Two methods of self-potential surveying, having a similar configuration to resistivity methods, can be performed. The dipole, profiling or gradient format utilizes two fixed electrodes spaced at distances equal to the station spacing. The normal mode of operation involves placement of the electrode in pre-dug shallow soil holes, observation of voltmeter potential electrical difference and leap frog movement of the trailing negative electrode to the next station location, leaving the positive electrode at the same location. The negative and positive electrode polarities are then re-established at the new location, negative trailing, positive leading.

The second method, fixed-base design, uses a stationary fixed base electrode arrangement where the measuring electrode is moved away from the base electrode to each station point on the survey line. A voltmeter potential is recorded for each station with the negative electrode always located at the fixed base. The resultant values for each configuration should be equal with the exception of a reduction of cumulative error in the fixed base method due to less time varying effect. Other advantages of the fixed base format are one man operation and better data reproducibility since station points are easily re-occupied.

Good field procedures for either configuration includes digging of placement holes with non-metallic implements for electrode placement, placement of the electrode within the zone of vadose moisture and cleaning of the electrodes before each placement.

3.2.8 Field Data Documentation

The equipment operator and survey coordinator must be aware of the importance of accurately recording data measurements, station locations and comments pertaining to survey interferences. It is recommended that a field plot, data sheet and voice recorded log be kept throughout field survey activities. As discussed previously, replication of SP data is difficult to say the least, particularly with respect to low amplitude anomalies, having 10 millivolt (mv) values. Therefore, survey accuracy is of tantamount importance. The following survey attributes should be documented: line and station location, the sign (plus or minus), and millivolt reading, weather conditions, time of day to the minute, cultural features, soil conditions, calibration variations, and conditions of placement of the electrodes. For archaeological investigations, it is recommended survey lines be preferentially orientated 90 degrees to known features of interest.

3.2.9 Data Reduction

3.2.9.1 Field

Data reduction in the field involves a profile plot of the uncorrected field data. SP values in + or - millivolts are plotted verses survey line station distances on an x-y axis. Obvious errors, interferences or requirements to reduce or expand station and line spacings can be visualized from these plots.

3.2.9.2 Office

All corrections to the data set are normally performed after the field surveying is completed. Individual station measurements are compared to the periodic reference electrode measurements to adjust the data for drift and electrode solution variations. Excessively noisy stations may also be deleted from the data set or compensated for, if a source can be verified. Plotting and connecting of the data points is again performed on an x-y axis for interpretative purposes. If the data curve appears spiky some smoothing or filtering of the data may be performed.

3.2.10 Interpretational Processes

Analysis of SP data is most commonly performed in a qualitative fashion by examination of profiles and contour plots. More structured, geometric source modeling may be conducted to determine depth, configuration and location of anomaly sources. The desired goals of the survey, available subsurface information and data quality will dictate which interpretative analysis is to be selected.

SP surveys conducted for mineral exploration, engineering and groundwater movement are generally interpreted through a modeling sequence. Geometrically shaped anomalies of varying depths, sizes, and amplitudes in the form of spheres, cylinders, vertical and horizontal sheets and line or point sources may be compared to the recorded data situated within a correct geologic regime. Recognition of the proper model requires many interpretative iterations and may be performed on a computer. It is important that the interpreter be cognizant of both the overall shape of the data, as well as, the small wavelength features to determine their significance. Interpretive complexities result where anomalies due to water flowage, soil changes, structure and mineralization overlap.

Examples of typical SP anomaly characteristics follow:

Feature	Sign	Amplitude
Increase in soil clay content	Positive	Small
Coarse gravel and sands	Negative	Small
Topographic increase	Negative	Small
Areas of faults and fractures	Negative	Large
Geologic Contacts	Sign change only	
Influx of groundwater	Negative	Small
Discharge of groundwater	Positive	Small
Mineralization	Negative	Large

Observed amplitudes can vary between ten to several hundred + or - millivolts.

SP surveying for archaeological purposes will be most closely utilized with a qualitative interpretation sequence. Small wavelength anomalies located in low noise areas may be detected by pattern recognition, based on available site information. In most instances structural features such as a wall or midden may be detectable due to near surface differential water flowage. For example, a porous wall may be observed as a small amplitude, negative feature.

3.2.11 Presentation of Results

Profiles and contour maps are the preferred format for presentation of SP survey results. A narrative describing sources of noise, both natural and man-made would be helpful to evaluate the survey success.

3.2.12 Special Considerations

The ease which a survey can be performed and low cost instrumentation make this an attractive surveying technique. Its potential value for archaeological surveying is limited by often complex interpretation requirements, rigors of reproducible field procedures and most importantly, numerous sources of noise. Careful field procedures are very important (clean, well placed electrodes, stable reference electrode bath and good documentation) to obtain meaningful data.

3.2.13 Required Expenditures

Self-Potential surveying instrumentation is inexpensive by comparison to other geophysical equipment. Porous pot metal-metal salt electrodes can be purchased for $150 for a set of three, a digital voltmeter for $100 and single conductor, insulated cable, $0.50 - $0.75 per foot ($1.65 - $2.50 per meter). A crew of two can cover 2000 linear feet (610 linear meters) of survey line, with two foot (0.61 meter) spacings, in one day.

When employing a contractor to perform a survey, approximately $0.50 per foot ($1.65 per meter) of linear surveying is a common cost. Interpretation of data and report of findings will require additional time and effort dependent upon survey complexities.

3.3 Gravitational Methods

3.3.1 Informational Discussion

The basis for a gravity survey is to detect and measure anomalies due to the gravitational field. Gravity surveying has several similar characteristics to magnetic surveying. Surveying is conducted at stations along survey lines, raw data requires corrections, (although gravity requires several more than on magnetic data), both methods are based on similar force laws, Newton's law of gravitation and Coulomb's law of magnetic attraction, and the interpretative sequence involves anomaly modeling through examination of profiles and contour plots.

If the earth was considered a homogenous sphere of uniform density, gravitational forces across the planet would be equal at all measurement points. This is not the case, due to horizontal density or mass contrasts in subsurface materials. Unconsolidated soils exhibit densities within ranges of 1.56-2.6 g/cm^3, sedimentary and igneous rocks may exhibit ranges of 1.55-3.0 g/cm^3 while some dense minerals have densities over 5.0 g/cm^3.

These contrasts provide a means of exploring for minerals and offer some exploitable applications for engineering and environmental investigations.

The gravitational force exerted on a mass attached to a lever and zero length spring arrangement allows relative measurement of changes in the acceleration of gravity. This measurement is accomplished utilizing an instrument termed a gravimeter. The units of gravitational measurement is termed Gal, where the gravity acceleration of the earth is 980 Gals or 9.8 meters/second^2. Standard gravimeters used in geological exploration are capable of measuring contrasts of 0.01 Gal. Micro gravity instruments can measure contrasts of 0.001 Gal anomalies and are primarily utilized in engineering or environmental investigations.

Gravity methods utilized for engineering and environmental studies are somewhat closely related to archaeological investigations. For archaeological purposes gravity methods have their greatest application in determining locations of subsurface voids, mapping bedrock and density determination of possible archaeologically related topographic features. The major problem of applying gravity methods to archaeological investigations is often related to insufficient signal to noise (s/n) ratios. A small s/n ratio results in the gravity method being incapable of detecting small density contrasts related to archaeological features. This sensitivity problem is not completely related to the gravimeter capabilities but is greatly influenced by raw data correction requirements, especially those related to small terrain corrections. Terrain corrections are capable of obscuring many archaeological features.

The methodology for conducting a survey is nearly identical to those of a magnetometer program. It consists of determining pre-survey objectives, acquisition of data with necessary precision, identify anomalies with respect to site context, and translation of findings to aid the investigation.

The field procedures consist of surveying on an established grid with station points separated by distances equal to one-half of the anticipated depth of interest. Micro gravity surveying requires elevation corrections within 0.4 cm, which are often very difficult to achieve. Generally, it is advantageous to calibrate instrumentation to a gravity survey benchmark. Reoccupation of a selected base point on an hourly basis or less, perhaps every 15 minutes for a precision survey, is required to correct for instrument drift. A base station gravimeter cannot be utilized due to variations in drift between instruments.

Uncorrected gravity data or raw field data normally does not provide inherently obvious information. An interpretation is possible only after the difference between the observed gravity is corrected for latitude, elevation, mass and terrain and compared to the theoretical gravity calculated at the station point, for a selected datum. After calculation of each value, indicated anomalies may be compared to specific source models. Since anomaly characteristics can be reproduced by numerous source configurations, interpretation is often ambiguous. Therefore, all site specifics, including data from other geophysical surveys should be incorporated into an iterative interpretation. Identification of anomalies can range from sophisticated to simple locating dependent upon data quality, objectives and budget.

Survey expenditures, manpower and time requirements are similar to those experienced in a magnetometer survey with exceptions. Additional expenses for precision station location surveys, more intensive data reduction requirements and expensive equipment, $35,000 for a micro gravimeter, contribute to increased costs averaging $1,500 - $2,000 a day for field work. Analysis involves several complex computer assisted data reduction routines, therefore an expenditure of $500 per day can be expected for report preparation.

To date, gravity surveys have seen limited use in archaeological investigations. In the future, it is believed this method will see expanded utilization due to the combination of accurate, satellite terrain surveying capability.

4.0 Active or Induced Techniques, General Discussion

A number of active or induced geophysical techniques have been perfected that are based on introduction of electrical currents, electromagnetic or acoustic energies into the subsurface. Interaction of these transmitted signals within subsurface materials alter specific properties or attributes of the input signal. Changes in signal related to amplitude, frequency, wavelength, and time delay properties may be observable. Earthen media is considered a relatively poor conductor of energy by most standards, significant amounts of the transmitted energy are lost or diffused into the subsurface. Often though, some small amounts of the returning energy can be detected utilizing appropriate geophysical receivers. These signals can be amplified, compared to transmitted signals and recorded in some manner for analytical purposes. By actual testing, theoretical consideration and modeling, subsurface material properties can be indirectly ascertained from the observed signals.

Active or induced techniques having applications to archaeological investigations include electrical resistivity, electromagnetic ground conductivity and ground penetrating radar. Acoustic or seismic techniques are also considered active methods, but at present, have very limited or specialized usages for archaeological purposes.

Metal detectors are generally configured in a form of either as active, electromagnetic conductivity meters or as a passive, vertical gradient magnetometer. The electromagnetic detector is the more commonly utilized instrument. It has the ability to detect ferrous, as well as other metals, whereas the vertical gradient magnetometer variety will only indicate the presence of iron.

4.1 Electrical Resistivity

4.1.1 Purpose

Geologic materials often exhibit a somewhat diagnostic impedance or resistance to flowage of introduced electrical currents. This electrical resistivity of a material or conversely, its ability to conduct electricity, is directly related to its porosity, permeability, saturation, and chemical nature of entrapped fluids. Measurement of these subsurface properties is accomplished by introduction of an electrical current of known intensity and frequency into the subsurface at a selected location. Observation of the resultant electrical potential at some distant point(s), provides a measurement of voltage loss due to the lateral and vertical variations of subsurface materials. Since many materials such as sands, gravel, and shales, exhibit non-unique resistivity ranges due to fluid saturation, knowledge of site geology is required to extrapolate resistivity data.

Often, particularly with regard to shallow archaeological investigations, observation of relative resistivity or conductivity lateral changes along a survey line are diagnostic irrespective of absolute intensities. Lateral changes are mapped by profiling techniques.

Observations of vertical variations in resistivity mapped by resistivity sounding techniques provide a means of detecting subsurface inhomogeneities at greater depths than profiling techniques. Normally, the very near surface nature of anthropogenic remains indicates the usefulness of the profiling methods for archaeological investigations.

4.1.2 Limitations

The usefulness of resistivity methods is primarily dependent upon anomaly or target characteristics. For archaeological investigative purposes where targets are generally small in size, resistivity value contrasts between target and surrounding materials are minimal or where background noise due to site conditions obscures features of interest, resistivity method will be limited. Interpretation of observed lateral variations in near-surface soil can be extremely complex due to these factors. Additionally, alteration of soil saturations or chemical ion properties such as caused by the addition of fertilizers, will affect observed subsurface electrical properties causing replication problems within a given time period.

4.1.3 Application

Both resistivity profiling and soundings have been utilized extensively for mineral exploration, engineering and environmental purposes. Mineral exploration and related uses include delineation of gravel, sand deposits and sulfide ores, detection of faults, and groundwater evaluation. Engineering applications have involved examination of the integrity of foundations, soil characteristics, void detection and permafrost delineation. Environmental usages include identification of landfill materials and subsurface contamination.

Resistivity profiling for archaeology purposes involves identification of nearly all forms of constructed features such as foundations or walks, compacted soils and excavations. Areas of humus, related to occupation, are also detectable.

The ease of resistivity data acquisition and observation of lateral changes across a site offers the archaeologist an attractive investigative tool, with respect to other geophysical methods. As with all techniques, its site specificity must be accounted for.

4.1.4 Equipment Selection

Basic resistivity equipment utilized for profiling and sounding consists of a battery or generator powered a.c. or d.c. current transmitter, digital voltmeter receiver, four electrodes and connection wire. Due to the d.c. nature of man-caused and naturally occurring (self potential) currents found in the earth, a.c. or pulsating d.c. current transmitters are commonly utilized to help eliminate noise interferences. The current source is attached by wire to the current electrodes, vertically installed copper or iron stakes. The digital voltmeter is utilized to measure the electrical potential across the potential electrodes. Typical current output for a small portable system is 20 milliamperes (ma), while a powerful generator system output may achieve 100 milliamperes.

Resistivity equipment requirements for archaeological profiling would in most instances consist of a highly portable, battery powered, low voltage system, since high power systems are utilized for greater depth penetration. One available instrument (Geoscan), using a twin dipole array, allows rapid acquisition of relative resistance, without measuring resistivity. A digital data logger is highly recommended as a method of recording observed voltage measurements. This will increase field data acquisition capabilities, reduce data reduction input time and provide a measure of quality control.

4.1.5 Pre-Survey Site Evaluation

Before traveling to the field, site evaluation and method criteria must be reviewed. The success of the survey is dependent upon:

- Determination of target size and depth of burial. This will determine preliminary survey line spacing, "a" spacing or spacing between electrode pairs and station spacing between measurement points along each line.

- Knowledge of geologic materials at the site, if available. This will provide a general range of resistivity contrasts to be expected.
- Observation of the weather patterns and resultant soil saturations that may offer the most conducive conditions for target recognition.

- Determine sources of potential noise, such as; cultural features, fences, pipelines, power lines, communications equipment, railroads and cropland usage (the presence of irrigation related salts in the soil) and secondly, naturally occurring noise produced by self-potentials, geology, lateral effects of topography and weather.

Upon review of these site-specific conditions, the chances of survey success may be estimated.

4.1.6 On-Site Compatibility Testing and Equipment Calibration

On-site testing will generally consist of configuring the electrodes in an acceptable array for profiling based on anticipated site requirements. Definition of an array is the manner in which electrodes are placed with respect to each other on the surface. For archaeological surveying purposes, a common configuration is a Wenner array where current electrodes are placed at the ends of the station with potential electrodes placed in-line between the current electrodes. The distance between each electrode is set to some "a" spacing distance usually equal to anticipated target depth. Other arrays may be selected dependent upon survey requirements. The most commonly used arrays are Schlumberger, dipole-dipole, pole-dipole and gradient.

Upon selection of an acceptable array, in this case the Wenner, tests are conducted by changing "a" spacings in a selected test area, hopefully free of interferences. Reoccupation of this location during the survey period will establish a baseline for the equipment and site. Additional calibration should be performed over an archaeological feature, if known, to ensure a proper "a" spacing, distance between stations and survey lines are attained.

A final check of all equipment including battery power is recommended before field acquisition begins.

4.1.7 Data Acquisition

The performance of a resistivity profiling survey requires the establishment of a survey grid where line and station locations are clearly marked. Generally, it is recommended the resistivity survey grid be orientated such that survey lines perpendicularly transect features of interest, whenever possible. Upon determination of the grid, the four electrodes are placed at respective locations dependent upon the selected array and at some "a" electrode separation, coincident with target depths.

For a Wenner array, one of the most common profiling electrode placement geometries, the four electrodes are situated as current -potential - potential - current with equal fixed distances or "a" spacings between electrodes. A voltage is introduced into the ground simultaneously at the current electrodes and a resultant voltage change in ohms (a measurement of electrical resistance) is observed across the center potential electrodes. The observed value is the apparent resistivity at the station. The value may be expressed in ohms resistance per unit of distance. The apparent resistivity is equivalent to a representative homogeneous isotropic half space of the subsurface. Since it is only representative, it is not a true or even an average of the resistivity values of the materials situated beneath the station. Subsequent comparison of observed apparent resistivities across the site allows identification of conductive or resistive inhomogeneities in the subsurface.

After a measurement is acquired at the first station the current electrode at the beginning of the survey line may be moved one "a" spacing past the second current electrode, in a leap frog fashion. Re-establishment of the proper current transmitter to current electrodes and voltage meter to potential electrodes is performed at this location, thereby reducing the need for movement or re-planting each individual electrode. Thus, potential electrode 1 becomes current electrode 2 and potential electrode 1 becomes current electrode 1 at the beginning of the second array. This configuration and movement is maintained along the survey line to profile completion.

It is important that, to ensure good instrument sensitivity and unwanted electrical interferences, electrode resistances be minimized. Accomplishment of this task often concerns electrode cleaning, placement into moist soil, wetting with salt water or burial of aluminum foil with the electrodes.

Upon completion of the survey, normally conducted by a two to three man field crew, observed apparent resistivities in ohms-meters are plotted verses "a" spacings on an x-y axis for each survey line profile.

4.1.8 Field Data Documentation

As in any geophysical survey, field documentation is extremely important. Commercially available resistivity, units normally are of two varieties, either capable or incapable of recording or storing measurements. In either case, it is recommended the operator record pertinent values, as well as, field comments on a data sheet. The recording of line, station, current intensity and potential can be efficiently performed as field helpers set up the next station. Operator review of written data sheet provides a measure of quality control in the field, to allow survey adjustments and rapid anomaly recognition. Data sheet comments should include; weather conditions, since nearby storm interferences can influence data, and observed sources of other noise.

4.1.9 Data Reduction

4.1.9.1 Field

At the end of each survey day, calculation of each station apparent resistivity can be quickly performed by the formula:

$$p = \frac{\Delta V}{I} \times K$$

Where I is the current, Δ V is the measured potential difference, K is a geometric factor dependent upon the array and p is the apparent resistivity. A plot of apparent resistivity verses survey line length by "a" spacing is performed for final data interpretation, in many instances.

4.1.9.2 Office

Since no additional data reduction is necessary after apparent resistivity calculations, office procedures may consist of data filtering developed from baseline data to adjust resistivity spikes or removal of known noise interferences. Production of a resistivity contour map may also aid in the recognition of subtle features.

4.1.10 Interpretational Processes

The recognition of archaeologically related subsurface inhomogeneities, with respect to profiling, is primarily qualitative. Adjacent lines and stations are visually compared to each other for observation of lateral changes. Thus in many cases archaeological feature interpretation will be related to pattern recognition and can be performed with relative ease. It is assumed additional knowledge of site characteristics is utilized.

Where site knowledge is limited, source modeling can be performed to produce non-unique data resolution scenarios. To aid in the interpretative process ground truthing of several observed anomalies is also required to determine the significance of other detected features. In all phases of the data interpretation, investigators must be aware that selection of improper "a" spacings may result in non-detection or produce unrecognizable anomalies.

Lastly, before completion of the interpretative process with respect to complex data sets, all possible interference affects should be considered. Some of these are: temperature, an increase in temperature decreases resistivity, variation of rock texture and rock types, local geologic processes, presence of clay minerals will decrease resistivity, percentage of water saturation and terrain influences. It is highly recommended as an aid to interpretation, known information be plotted upon the profiles at their indicated locations, This should include topographic elevations and geologic changes, as a minimum.

As anthropological activities have somewhat similar attributes of geologic processes, consideration of their general effects on resistivities are useful to review.

Process	Resistivity
Weathering (excavation)	Decrease
Faulting or fractures	Decrease
Clay increase	Decrease
Water influx	Decrease
Dissolution	Decrease
Silicification	Increase
Mineral Precipitation	Increase
Induration (compaction)	Increase
Temperature Increase	Decrease

Resistivity surveying, when utilized independently of other information, may not provide definitive data.

4.1.11 Presentation of Results

Resistivity survey data is presented in a format similar to magnetic, gravity, conductivity and SP data. Profiles, contour maps and descriptive narrative are generally provided upon project completion. As previously stated, all available information should be plotted along the profile as an interpretative aid.

4.1.12 Special Considerations

Caution is required in handling of wiring and electrodes while connected to the current transmitter, particularly high power generator systems; electrical shocks are possible. Also, due to connective ground wires and planted electrodes, electrical storms can be dangerous to equipment and crew members. Lastly, be aware of sources of noise, particularly those related to electrical interferences.

4.1.13 Required Expenditures

Even when utilized as a reconnaissance tool at an archaeological site additional surveying effort is required to assure target recognition. Small "a" spacings require many equipment moves, therefore, survey costs will be high, perhaps in the $1500/day range when performed by an experienced three man crew. Distances covered in a day may be in the 1000 foot range. Purchase of a limited memory recording instrument is estimated at $3,500 - $15,000. Instrument rentals of $35 per day can be expected.

4.2 Electromagnetic Conductivity Surveying

4.2.1 Purpose

Electromagnetic methods, often referred to as EM or induction, provide a means of measuring near surface conductivity. A measurement is obtained by inducing an electromagnetic field into the earth causing an electrical current flowage, similar to that obtained in a resistivity survey. Utilizing a non-surface contacting transmitter - receiver arrangement, the interaction of the generated circular eddy current loops or electromagnetic field with earthen materials is directly proportional to terrain conductivity within the influence area of the instrument. Conductivity is measured in units of millimho (mmho) per meter of material, it is the reciprocal of resistivity. Therefore, the information provided by a conductivity survey should in theory produce similar results to that of a resistivity profile survey. Generally, the transmitter-receiver instrument is calibrated such that the earth is considered to be homogenous. Where the earth is layered, the instrument will measure an average value over the depth of investigation interval. Therefore, the usefulness of conductivity surveying is its ability to detect lateral changes in subsurface materials. The main advantage of terrain conductivity surveying over that of resistivity profiling is the non-surface contact feature. The instrument can be moved from station to station by a single operator. Whereas, for resistivity surveying a crew of three or four is often required to move and place electrodes along a profile line, EM surveying requires one or two crew members.

4.2.2 Limitations

Instrumentation, as well as, electromagnetic interferences are limiting factors capable of affecting the usefulness of the method.

Currently available instrumentation consists of instruments normally constructed with fixed distances between the transmitter coil and receiver coil. The extent or size of the electromagnetic field or loop introduced into the ground is determined by these coil separations. Since this loop intercepts the earth over a restricted area, no adjustment for target depth can be realized with the exception of varying instrument height. In some cases, limited depth information can be acquired if the coil orientations are changed (parallel or perpendicular) to the ground surface. Also, the measurement taken over this area is an average of all ground components or constituents. Since archaeological features may influence this average to a small degree, features of interest may be poorly defined. Luckily, archaeological features are normally near surface phenomena. One available instrument, having a fixed coil spacing of one meter, is extremely useful in archaeological work.

Electromagnetic interferences and the nature of the induced field also are limitation factors. Modern cultural interferences that fall into the sphere of influence of the induced field will be averaged into the measurement. These features, such as buildings, fences, buried objects and utilities, must be accounted for. Likewise, the nature of the electromagnetic field and its interaction with the ground can limit its usefulness. Areas exhibiting high conductivities may not maintain a reliable ground conductivity value. In other areas of low terrain conductivity, it may become difficult to induce an electromagnetic field with any instrument. Measurement sensitivities in the range of 2-2000 ohm-meter or 0.5-500 millimhos-meter are practical with available instruments, covering a useful range of soil resistivities. Lastly, due to a proportional reduction in the induced field strength with distance, near field materials will greatly affect the observed measurement. Various instrument tests indicate perhaps 65% of the averaged measurement value is attributable to constituents within the first third of the electromagnetic field influence area.

4.2.3 Applications

The ease of operation and sensitivity of the method to buried metallic objects, soil contamination and water saturation has resulted in widespread environmental and engineering EM applications. Likewise, EM has also realized a general acceptance within the archaeological community as an exploratory tool. The ability of the method to detect lateral changes on a rapid data acquisition, high resolution basis, where observable contrasts exist, are its major advantages. With respect to buried anthropogenic features, lateral changes due to compaction, structure, buried metallic objects, excavation, habitation sites, and other features affecting water saturations should be observable. Also, the ability of the method to detect all conductive metals provides an advantage to more selective, iron locating magnetic methods.

EM methods in mineral exploration are also widely used. Large instrument arrays are often flown at low altitudes over large areas in the exploration for high conductivity anomalies associated with base metal and precious metal deposits.

4.2.4 Equipment Selection

Conductivity equipment consists of a low frequency, time varying radio transmitter-receiver arrangement incorporating a voltage meter. The voltage meter, calibrated to read conductivity, allows observation of an output voltage that is linearly proportional to the conductive coupling effects of the subsurface material within the transmitter-receiver influence. A spherical area around the transmitter-receiver coils is investigated, the size of which is determined by coil separation distances.

Archaeologically related conductivity anomalies are generally near surface, relatively small, occupying a small volume, and are probably not very conductive, if they are of a non metallic nature. Therefore, equipment must be capable of providing a highly sensitive measurement of a relatively small volume area. To accomplish this, coil spacings must be small, on the order of 1-4 meters in length. A one meter coil spaced instrument, such as a Geonics EM 38, held vertically at a height of 30 CM above the surface is capable of 1.5 meter investigate depth. Thirty five percent of the instrument response occurs below one meter. A somewhat larger coil spacing of 3.7 meters (12 feet) is available in the Geonics EM-31 model. This instrument averages conductivity measurements over a much greater soil volume, to a depth of approximately 6 meters or 18 feet. However, the Model EM-31 may not provide sufficient sensitivities to detect small volume, non conductive materials.

Utilizing a one meter coil spacing across a site on a one meter station interval will result in a significant number of measurements. In some investigative cases, one foot spacings may be required, further increasing the number of measurements. To facilitate recording such a large number of measurements it is recommended a digital recording device, such as a Polycorder Data Logger be employed. Acquired data can be down loaded to a computer upon survey completion.

4.2.5 Pre-Survey Site Evaluation

As in all geophysical investigations, pre-survey method compatibility evaluation is necessary task. Survey objectives must first be defined. The size, depth, frequency of target occurrence, and its nature or composition should be evaluated. Since measurements are acquired or observed either continuously or on a station to station basis, a location grid system must be established, according to target defined parameters. Coil spacing selection will be defined by anticipated target depth.

The evaluation should include:

- Identification of cultural related interferences.
- Line and station selection to maximize likelihood of anomaly detection.
- Design program to observe known features, as well as, areas devoid of features for control purposes. Survey lines should extend sufficient distances to pass beyond anomaly limits.
- Since a large number of measurements can be acquired in a day (1200-1500 on a station basis) arrangements to observe data on a daily basis is recommended.

Overall, the performance of a site evaluation is most similar to magnetic surveying, since design and interferences are similar.

4.2.6 On-Site Compatibility Testing and Equipment Calibration

Instrument absolute calibration is normally conducted at a base station established by the equipment manufacturer. The conductivity is known at this location to a depth equal to the instrument coil spacing investigative depth. In the field, an equipment operator will normally establish a base station to ensure proper equipment operation over the survey period. Measurements at this station should be consistently reproducible.

Initial functional procedures for the selected instrument involve checking battery condition, zeroing the instrument at its least sensitive millimhos/meter selection and checking the instrument sensitivity to ensure the optimum measurement scale.

4.2.7 Data Acquisition

Acquisition of measurements is a straight forward process, similar to other geophysical profiling surveys. Measurements can be made along a profile line, on a station to station basis or continuously. For archeological surveys, where targets are small or shallow, overlapping stations may be required. This may be accomplished by reducing the distances between lines or stations. This spacing reduction allows the electromagnetic field or investigative area of the instrument to overlap. The decision as to the correct spacing will be dictated by recognition of the lateral dimensions of observed anomalies. After collection of data from a few profiles, the operator should anticipate these dimensions and adjust survey parameters accordingly.

During the survey the instrument should be positioned at a constant height above the ground surface. This will limit interferences due to measuring small or greater volumes of the subsurface if the instrument is varied in height. At each station the instrument should be consistently orientated in the same direction. A rotation of 90 degrees will identify lateral inhomogeneities, if they exist. This is particularly important since a buried wall, for example, will exhibit a significant measurement variation if the orientation of the instrument is parallel to or perpendicular to the feature. To compensate for recognized orientation problems, it is recommended two measurements be acquired at each location, preferably at observed maximum and minimum conductivities. These measurements can be plotted as an average value or may be plotted independently.

Large meter fluctuations, negative or positive, are indications of highly conductive subsurface materials, possibly related to utilities or other cultural interferences. Observation of the extent and orientation of the associated anomaly may provide the operator insight as to the characteristics of the feature. The equipment manufacturer recommends determination of the affects of nearby cultural features by checking orientation and influence distances. The operator may move away from the cultural feature until its affects are minimized. Besides cultural influences, the operator should be aware of electrical storm activity as it may cause meter readings to fluctuate beyond acceptable noise levels.

4.2.8 Field Data Documentation

As stated previously for large surveys, all measurements, line numbers and station locations can be digitally recorded to a data logger. For small surveys a written record of line, station and measurements will suffice. No matter which method of documentation is selected, survey comments should be explained with sufficient detail to aid in the interpretative process. These comments should include location of cultural interferences, weather and observed geologic features.

4.2.9 Data Reduction

4.2.9.1 Field and Office

In most cases very little data reduction is necessary when the primary purpose of the survey is to observe lateral variations rather than absolute conductivity values. Due to instrument response, calculation of true conductivities requires a correction for measured apparent conductivities, above 100 millimhos/meter. Calculation of resistivity is a relatively simple matter. It is obtained by dividing the true conductivity by 1000, resulting in unit values of ohm-meters.

Generally a graphic profile or contour map depicting apparent conductivity verses location is the final data reduction product. This can often be performed in the field, if a computer is available, or upon return to the office.

4.2.10 Interpretational Process

The interpretation of spatial variations in conductivity values is normally a qualitative one. Since we are interested in detecting a change from a relatively constant background, both positive (increases) and negative (decreases) in conductivity can be of significance with respect to an archaeological investigation. Survey results from an undisturbed area indicating a gentle variation in ground conductivity might be expected, if no radical change in subsurface composition or layering occurs. Where a subsurface disturbance is superimposed upon this background a positive or negative anomaly may be discerned, dependent upon the features conductive characteristics. Ultimately, as a result of the proper selection of survey parameters, pattern recognition or signature becomes an important factor in determining the archaeological significance of a detected anomaly.

Within areas of noisy background fluctuations caused by cultural, geologic or other circumstances, features of archaeological interest can easily be obscured. Therefore it is important that survey results be integrated with all available project information. As is evident from previous geophysical method discussions, development of a model based on field observations and theory would aid the interpretative process.

Conductivity survey results across selected sites are often variable. Changes in subsurface moisture are often the cause. Buried, conductive metals are most often observed as sharp, positive spikes in data sets.

Electromagnetic terrain conductivity methods may replace resistivity methods in archaeological investigations. Even with the relative high cost of EM verses resistivity equipment, the time, manpower and accuracy differentials favor EM methods. One advantage resistivity methods do have over conductivity methods is the ability to vary electrode spacings. This ability allows the investigator to adjust acquisition parameters for optimum data recovery.

4.2.11 Presentation of Results

Results of non grid conductivity surveys are presented as graphic profiles where conductivity values are plotted against station distances along the profile. High density grid data is presented either as shaded intensity plots or as iso-apparent conductivity contour maps. A narrative describing survey parameters, objectives and a discussion of results should also be included in the report.

4.2.12 Special Considerations

The equipment operator should be continually aware of nearby conducting features and sources of electromagnetic noise. Data should be observed during survey activities to ascertain if survey objectives are fulfilled with regard to anomaly detection.

4.2.13 Required Expenditures

Commercially available equipment currently (1992) has a cost range of $6,500-13,000. Acquisition of a highly recommended data logger will require an additional expense of $4000. Cost for a contract two man crew is approximately $1000/day. A normal acquisition rate of 1000-2000 stations can be maintained over a dense grid area. Data reduction and interpretation should be in the $500/day range. EM equipment can be rented at an approximate cost of $25-$50 per day. Rental of a data logger is also highly recommended. They are available at a cost of $30 per day.

4.3 Ground Penetrating Radar Surveying Methods

4.3.1 Purpose

Ground penetrating radar, often referred to as GPR, is an active electromagnetic subsurface investigative method. Having attributes of seismic reflection methods, it is used most often in the reflection profiling mode for archaeological purposes. Its operation is based on introduction of a relatively low frequency electromagnetic signal, generally in the 80-1000 megaHertz (mHz, millions of Hertz) range, into the ground via a surface contact transmitting antenna. As this signal passes through the earth it may encounter subsurface materials of varying electrical impedances or properties. At these electrical interfaces, the signal may either be reflected or attenuated, being more or less dissipated into the material.

The reflected signal, when detected by a receiving antenna at the surface within close proximity to the transmitter, can be compared to the original input signal. Comparison of the signal delay time, normally in the 10-4000 nano second range (ns, billionths of seconds) is a function of the speed or velocity of the signal in the subsurface as it passes through the material, reflects, and travels back to the receiving antenna. The time it takes to do this is referred to as two way travel time (TWT) or transit time. Observation of the two way travel times allows a calculation of subsurface velocities. Ultimately, if a target of known depth is compared to a surveyed feature or if an assumed host material velocity is utilized, burial depth can be determined.

The magnitude or amplitude, phase (negative or positive), and frequency of the received signal offers additional information as to the nature of the subsurface materials. In many instances a strong reflected signal may be observed originating from a buried metallic object. Undisturbed, layered soil materials will generally be observed as horizontally orientated radar event interfaces.

In other cases where the radar signal is dissipated into the subsurface as a consequence of electrical properties, no reflections, or little radar penetration may result.

4.3.2 Limitations

The variability of subsurface electrical properties determine the propagation of radar energy through geologic materials. Therefore, adverse subsurface conditions limit its usefulness on a site specific basis. Water saturations and the chemical nature or activity generally control the dielectric and conductive properties of the materials. High conductivity situations will result in attenuation and a reduction in signal velocity or strength, causing a decrease in depth penetration or observable reflections. Subsurface reflections may be unattainable where there is a lack of electrical property contrasts. The presence of highly conductive clay materials for instance, in concentrations of ten percent or more, is probably the greatest limiting factor affecting the usefulness of the radar method.

Operating conditions also can affect the outcome of a survey. Access to the site and interfering obstacles must be accounted for. Normally, low frequency antennas are relatively unshielded and will radiate energy in all directions. Therefore above ground objects may cause reflections to occur at various time-depths equal to the distance the radar signal will travel through air to the object. These interferences often obscure subsurface reflections of interest. Also, due to the of the antenna being in contact with the surface a rough or bumpy ground surface may alter data characteristics. Occasionally, when surface conditions are extremely rough, the antenna may be slightly elevated above the surface on a platform and carried across the site. Radar data acquired in this fashion will require corrections for addition of the intervening air layer above the ground surface. Testing to verify the outcome of such actions is recommended.

4.3.3 Applications

GPR has effectively mapped soil layers, depth of bedrock, cavities, voids, rock fractures, ice thicknesses, and buried stream channels. In engineering and hazardous waste environmental studies, it has been utilized to locate and delineate areas of buried waste materials, contaminant plumes, buried utilities and examine concrete structures. Archaeological uses have included examination of burial sites, buried structures, detection of metallic objects, and other related anthropogenic features.

4.3.4 Equipment Selection

Several varieties of radar equipment are available, based on surveying requirements. The most common in usage today, having particular application to archaeology, is the reflection profiling system. This typical ground penetrating radar system consists of an antenna, radio wave form control deck, graphic plotter and digital magnetic tape recorder. Selection of antennas, having weighted center frequencies of 80, 100, 120, 300, 500, 900 and 1000 megaHertz (mHz), are utilized dependent upon site conditions and survey requirements. Greater depth penetration is obtained from lower frequency antennas due to generation of a longer signal wavelength than that of the high frequency equipment. Because higher frequency antennas have shorter signal wavelengths they are capable of resolving smaller targets or interfaces with greater accuracy.

Other systems are available which operate in more specialized modes such as transillumination, common midpoint, and wide angle reflection. The usage of these modes of operation in archaeology is limited.

4.3.5 Pre-Survey Site Evaluation

The performance of a ground penetrating radar survey requires some thoughtful evaluation before entering the field. Evaluation of field conditions as to surface access must first be referenced. This should involve establishing profile line locations to avoid obstacles, rough ground surfaces or adverse topographic conditions.

The next phase of the evaluation, perhaps more difficult, is to acquire a knowledge of the composition of the subsurface materials. This can be done through site observation or geologic research. If a clay composition or high water saturation is suspected, abandonment of the survey should be considered.

Finally, if all other factors indicate the survey could provide beneficial information, target size and depth must be determined. This will dictate the profile line spacing, survey orientation and antenna frequency. Since continuous profiling is performed, radar data is acquired over the entire length of the survey line, station distances can be marked at convenient intervals. Activation of a marker signal, which is transferred to the graphic record, is performed as the antenna passes each surface location mark.

4.3.6 On-Site Compatibility Testing and Equipment Calibration

Experience has shown, though the pre-survey evaluation may indicate poor results, on-site testing is highly recommended. The testing should include acquiring profiles over known targets where burial depths are accurately known. Also, this study should include using several different frequency antennas. Optimum depth penetration verses object resolution can be determined. More than one antenna may be selected to satisfy overall project requirements. After performing these field tests, it should be obvious to the operator whether or not useful radar information is obtainable at the site.

Where the depths to objects or features are not known for calibration purposes, a test bed may be constructed. This may consist of burying objects at measured depths within a suitable location and passing the antennas over the surface. This type of test should allow the operator to determine the applicability of ground penetrating radar to the site survey.

Other calibration requirements involve; optimize the time-depth range of the instrument in nano seconds, as determined by target depth, and adjustment of time varying signal enhancement gains. Radar signal loss or dissipation increases with depth. Random noise also increases with depth, often obscuring reflectors of interest. To overcome these problems an adjustment to the variable gain provides a means of enhancing or increasing reflected signal strengths from deeper occurring interfaces or anomalies. Deeper targets may be observed with greater ease through proper gain adjustment.

4.3.7 Data Acquisition

A site characterization survey using GPR provides a continuous cross sectional picture or profile of shallow subsurface conditions. The generated profile is a graphic plot of time in nano seconds on the vertical axis verses a corresponding surface location on the horizontal axis. In most instances, for field surveying purposes, a two man crew consisting of an equipment operator and antenna handler is required to operate the equipment. A survey grid of parallel lines may be established across the site with line interval spacings of five to ten feet (1.5-3.0 meters). Along each profile line, location marks can be situated at convenient station intervals, generally on the order of five feet (1.5 meters). The antenna handler actuates a location marker switch as the center of the antenna passes over each station location. The actuation of this antenna switch puts a corresponding fiducial mark on the radar graphic plot for reference with surface locations. As the radar antenna is moved across the land surface electromagnetic energy is radiated downward into the subsurface at a selected rate of 25.6 radar scans per second. A receiving antenna, commonly incorporated with the transmitting antenna, receives radar signals reflected back from lithologic or anomalous variations found in the subsurface. The data will most often be displayed in the field on a graphic plotter. The responses may also be recorded to magnetic tape for future computer analysis. The equipment operator will normally make notations on the graphic plot describing line location, time depth range in nano seconds, antenna frequency, direction of movement, horizontal scale, and any other pertinent information. This may include geologic information, surface conditions, interferences, and location of archaeological features.

Electromagnetic responses are generated at the interfaces of materials having different electrical properties. Reflections, or their absence, can often be related to natural hydrogeologic conditions such as; bedding planes, mineral cementation, moisture changes, clay content, voids, fractures, and intrusions. Man made objects or disturbances may also be observed in the subsurface as well. Often field data may be processed and enhanced prior to interpretation by computer processing.

The nature of the GPR method offers a number of advantages over other geophysical methods. The continuous vertical profiling produced by GPR permits rapid data gathering along a traverse line with excellent detail. The rapid data collection allows for the possibility of cost effective total site coverage. In some cases, the antenna can be towed behind a vehicle at speeds up to 10 MPH (16 kilometers per hour). In areas requiring high resolution or places having difficult topography, the antenna can be towed by hand. Subsurface resolution, dependent on antenna frequency input, ranges from centimeters to several meters.

4.3.8 Field Data Documentation

As the antenna is moved along the profile a location marker button is actuated at selected footage distances by the antenna operator. This mark is transferred to the graphic output strip chart electronically. The instrument operator will normally mark these locations with proper footage or meters, also indicating any observable interferences or site related information. Since the interpreter will examine each recorded profile, these annotations are extremely important. They can include location of: cultural features, vegetation, topographic or soil changes, geologic information and archaeological features. Additionally, all data characteristics such as range in nano seconds, antenna frequency, direction of travel, horizontal scale, line orientation, starting and ending points, and an estimation of applied signal gains can be annotated on each graphic profile.

As the interpreted information will most likely be transferred to a site map, line, footage (meters) or station location, and direction must be accurately recorded. Also, all recording parameters such as antenna frequency, time-depth and horizontal output scales should be provided.

4.3.9 Data Reduction

Generally, with the exception of performing computer color enhancement and filtering of data, in the office, little data reduction is required. The most obvious data reduction involves conversion of the nano second time scale to an apparent depth in footage or meters. Since penetration is dependent upon material properties, knowledge of radar signal propagation in soil materials is helpful. The preferable method, and probably the most site specific, easily obtainable depth information, can be determined by comparison of detected features with known test target information. A second method involves, if the nature of geologic materials at the site are well known, comparison with calculated standardized radar velocities obtained from geologic material tables. The velocity of a radar signal in air is 1 nano second per foot (0.3 ns/meter), dry sand 2-2.4 ns/ft (6.1-7.3 ns/m), wet sand 5.5 ns/ft (16.6 ns/m), and saturated clay 2.8-3.3 ns/ft (8.5-10 ns/m). Utilizing these numbers and others, a rough estimate of depth can be determined. A listing of additional radar velocities is provided for review in Appendix D. A third method involves a mathematical calculation, if the dielectric properties of the materials can be determined.

4.3.10 Interpretational Process

Data analysis involves examination of all the graphic profiles, individually and collectively. Experience is the key factor in the interpretative phase. Numerous changes are often observable along profiles at various time-depths. Variations in signal amplitude, phase and frequency, either subtle or obvious, must be accounted for. Often the uninitiated will view the profile as a geologic cross section. Realization that this is not the fact is a first step in understanding the data set. The features observed are changes in electrical properties; they may coincide with local geology and then again, they may not. In many cases the primary observable changes in data character may be related to water saturation where geology remains unchanged.

Normally, interpretation involves observation of anomalies within generally flat or horizontally layered radar interface events. Plotting of these features from profile to profile may allow recognition of archaeological related features. Since archaeological features often affect water saturation in the subsurface or may be of significantly different composition of the host material, they may be excellent radar targets, if subsurface conditions permit observation of contrasts. Overall, the general approach is to observe anomalies from the normal background data. To aid this process, ground truthing or excavation of observed features is highly recommended as the survey progresses.

Computer enhancement and processing during the interpretative phase is most useful where subtle features are to be examined. In cases where features are rather obvious no computer processing is recommended. Several radar profiles exhibiting typical radar responses to subsurface features are provided in Appendix D.

4.3.11 Presentation of Results

Results are often presented in the form of graphic strip chart plots. Remembering these are often the actual field plots, they may be in relatively poor condition. Where data is acquired on magnetic tape (recommended), plots can be regenerated at different scales or input to the computer for signal enhancement and display in color formats. A narrative describing survey procedures, maps depicting detected anomalies and annotated profiles should be supplied, probably within a month or so after completion of the field survey.

4.3.12 Special Considerations

Transmission of microwave energy (radar) has been designated a long term health hazard in certain instances. Otherwise other considerations involve keeping the antenna off the cable while surveying, being aware of cultural features, particularly power transmission lines, and while utilizing an unshielded antenna, observing reflections due to nearby, above ground features. It is difficult to negate or filter the effects of electrical or static interferences caused by radios or microwave towers.

4.3.13 Required Expenditures

Radar surveying is most certainly one of the more expensive geophysical methods having archaeological applications. Instrumentation costs range between $22,000 to $80,000 for a profiling system. Systems are available for rent in the $150/day range, when they are available, and require additional mobilization/demobilization and shipping costs.

Since radar is a relatively new geophysical phenomenon it can be difficult finding experienced contractors. A normal cost for a two man field crew ranges between $1250-$1500 per day. Dependent upon field access and survey requirements as little as 1000 linear feet (325 linear meters) may be collected in a day. Under excellent acquisition conditions 5-10 miles (8-16 kilometers) of data have been acquired in more exploratory situations towing the antenna behind a vehicle. Calculation of interpretation expenses is often difficult due to the complexity and volume of data. Generally a fee of $350-$500 per office day can be expected with the high end including some computer processing. Generally two days of interpretation time is allocated for each day spent in the field.

Ground penetrating radar is an extremely useful archaeological investigative method, where subsurface conditions permit its usage. Its relative shallow investigative depth, high resolution, sensitivity to soil disturbances, and in most instances, ease of data acquisition overshadow its relatively high cost.

4.4 Metal Detectors: Where Do They Fit, Discussion

4.4.1 Purpose

Numerous varieties of metal detectors, developed primarily for the treasure hunter or utility locating professionals, are available. Their construction or operational configurations are similar in nature to electromagnetic or magnetic geophysical instruments. The ability of equipment to locate iron or metallic objects within the upper few feet of the surface [illegible] simple mode of operation, and inexpensive nature offer the archaeologist a [illegible] useful investigative tool.

Utilization of a detector in combination with other more sophisticated survey methods has often proved invaluable. Its usefulness may be realized not so much in identifying significant archaeological features, though it is not unheard of, but more for determining shallow geophysical survey interferences related to recent cultural activities. An informal or more formal grid metal detector search can be quickly performed across a site during the initial visual site inspection. It is a highly recommended procedure. Whereas, most professional exploration geophysicists consider the metal detector quasi geophysical equipment, its usefulness to engineering or environmental geophysical investigators is apparent.

4.4.2 Limitations

Electromagnetic and magnetic detectors are generally useful only for investigation of the upper few feet of the surface. Nearly all systems provide an audible tone indicator either transmitted to headphones or to an external loud speaker as a qualitative measurement of the presence of a metallic object. Newer instruments are configured to provide a visible absolute or relative scale of signal amplitude. Due to instrument configurations, the field or area of investigation of individual detectors can vary, thus affecting instrument sensitivity and consequently discrimination of object size and depth of burial. In some cases, a small shallow object may produce the same instrument response as a larger deeper buried object. All instruments are subject to signal recognition interferences due to any nearby metallic objects.

4.4.3 Applications

Metal detectors are useful for identification of metallic objects within a few feet of the surface. Electromagnetic varieties are generally capable of detecting all conductive metals. They are configured with a radio transmitter-receiver coil arrangement similar to an EM terrain conductivity meter. Magnetic locators are configured in the form of a vertical gradient magnetometer or gradiometer. They are only capable of detecting iron objects. Besides utilization by treasure hunters, very sophisticated alkali-vapor detectors are currently employed for military ordinance locating. Other less sophisticated systems are used for utility locating and hazardous waste receptacle identification.

4.4.4 Equipment Selection

Essentially three (coil head, two box, and magnetic) types of equipment are available. Electromagnetic models are configured as two box or coil head, sensor systems. The two box consists of a three foot (approximately one meter) long rod fitted with a transmitter on one end and receiver box on the other. This system is sling carried several inches above and level to the ground surface. Movement out of level due to surface topography will produce an instrument response. Depth and area of investigation is about three feet. Due to this relatively large area, the sensitivity of the instrument is relatively poor. All conductive metal should produce an instrument response within the two box system.

The coil system consists of a control box situated on the end of a four foot long rod. At the opposite end, a thin dish shaped sensor head is positioned one inch above and parallel with the ground surface. Many of the coil systems offer interchangeable sensor heads of various diameters. Larger diameter heads are capable of greater depths of investigations normally in the 24 inch (60 centimeter) range. These instruments are designed with a radio transmitter located in the central area of the circular sensor head. The receiving element is located around the outside edge of the sensor head. These instruments are marketed primarily to treasure hunters for both land and underwater applications. Many have options for setting instrument sensitivities to selectively examine for all or individual metals based on electrical conductance.

Magnetic configured devices are somewhat similar to magnetic gradiometers. Two magnetic sensors are stacked vertically, normally within 18 inches of each other. Both sensors will detect a buried iron object as the instrument passes over. The lower sensor will produce a greater response due to its closer proximity to the object than the upper one. If the object is small, the upper sensor may not respond to it at all. The cumulative electrical potentials generated at each sensor produce an audible instrument response. The instrument will respond to either the mono or dipole magnetic field configuration signature of an anomaly. This type of detector is very sensitive to iron objects only, to depths of eight feet. Partially oxidized iron will also cause a response in most instances.

Occasionally, some metal detector instruments may respond to nonmetallic buried features such as an excavation or material having a significant composition change from the host material. This may be detected as a tonal change in the instrument response. Excavation is recommended at several of these anomalies to determine their significance.

4.4.5 Pre-Survey Site Evaluation

No evaluation is necessary as this method is considered a cursory site screening technique. Knowledge of cultural related interferences such as utilities would be helpful.

4.4.6 On-Site Compatibility Testing and Equipment Calibration

No site testing is normally performed, but an equipment calibration is recommended to determine the effectiveness of the metal detector. This is best performed by passing the instrument over known buried objects to acquire a knowledge of equipment response.

4.4.7 Data Acquisition

A metal detector search should be conducted in a systematic manner. Object size, depth of burial and metallic characteristics will dictate search sweep radii and type of instrumentation, electromagnetic or magnetic. If a survey grid is established, the detector may be walked along each line extending or swing the instrument back and forth over a comfortable distance in front of the operator. In unmarked areas, the operator may search utilizing a paced grid, observing or lining up with some distant site features to stay on line. Since no survey recording is performed, nonmetallic markers can be dropped at instrument response locations for later documentation or more detailed examination.

4.4.8 Field Data Documentation

Upon completion of the metal detector sweep, location of instrument responses should be surveyed into the site plan. Plotting of this information and incorporation into other geophysical data sets is considered a recommended procedure.

4.4.9 Data Reduction

No data reduction is performed due to the nature of the survey.

4.4.10 Interpretational Process

Survey results are most appropriately examined in the field upon survey completion and plotting of the observed anomalies. Interpretation of the detected features can only be attempted after ground truthing or excavation of a significant number of anomalies is performed.

4.4.11 Presentation of Results

Results are normally presented in site map form.

4.4.12 Special Consideration

While utilizing magnetic or two box metal detectors, the operator should be clean of iron or metallic objects. Two box and coil sensors must be held level with the ground surface at a prescribed elevation above the ground.

4.4.13 Required Expenditures

The performance of a metal detection survey is highly recommended for all suitable archaeological sites. Its ability to define possible areas of interest or identify more recent cultural interferences make it a worthwhile stand alone endeavor. When used in combination with other surveys, it also provides easily acquired, useful information. Basic instrumentation having archaeological possibilities can be purchased for $350 to $2000. More sophisticated high resolution equipment, such as utilized in ordnance detection, will cost approximately $17,000. Rental of metal detectors are possible at a rate of $10 per day.

5.0 Marine or Submerged Geophysical Considerations

Several geophysical methods can effectively be used to investigate submerged sites. Acoustic and magnetic surveying, primarily developed for military, exploration and engineering purposes, have been utilized to discover and investigate numerous shipwreck sites, as well as, submerged engineered structures in both fresh and salt water environments. Ground penetrating radar, useful in freshwater (but not salty or brackish waters due to high signal attenuation factors), has seen experimental usage in relatively shallow freshwater situations. Gravity surveys have been performed over large ocean areas for mineral exploration purposes.

Useful acoustic methods evolving from early 1960's work, consist primarily of side scan sonar, tuned transducer, color fathometer and slightly lower frequency, sub bottom profiler. Side scan sonar emits and receives reflected high frequency acoustic pulses in the 50-500 kilo Hertz (kHz) range from targets across the sea floor. It produces a chart recorder image approaching aerial photography in detail and coverage out to distances of one kilometer. Sub bottom profilers and other fathometer systems operate very similarly to side scan with respect to source and receiver. They are different in that they use of lower frequency energy transmissions, in the 5-50 kHz range, and downward signal beaming to reflect off or penetrate the seabed.

In operation a tow fish is pulled behind the support ship at a prescribed depth, dependent upon bottom topography and surface sea conditions. Loran navigational information is normally printed to the chart for positioning. For lake bed searches, smaller remote control systems are available, or a side scan fish can be towed behind an inflatable boat. Overall, side scan sonar has proven to be useful for shipwreck identification, investigation of ancient submerged harbors and engineering purposes.

Sub bottom profiling methods are performed with lower frequency acoustic transducers, and acoustic sources called sparkers or boomers. The lower frequency, longer wavelength signal is capable of penetrating the bottom sediments to depths of 50 feet to provide a shallow high resolution sea floor cross-section. These systems are primarily utilized in sea floor hazard studies and other engineering applications. Whereas, all these methods utilize an acoustic source and receiver system, they should not be confused with or lumped together with conventual seismic reflection or refraction methods.

Magnetic surveying is performed in a systematic manner similar to a land survey. Since perturbations in the total geomagnetic field are sought, similar anomalies should be observable in a water environment. Generally fluxgate or alkali-vapor magnetometers are utilized to provide continuous profiling capabilities, over the area of interest. The magnetometer can be deployed either by ship or aircraft. Magnetic surveys have been primarily used to detect shipwrecks, active submarines and other military targets or supplement marine seismic surveys. Most marine surveys are conducted with a two sensor gradiometer system since temporal variation corrections require a stationary magnetic base station. Also, since the ship is generally magnetic, the sensor is towed hundreds of meters behind the ship. With the advent of global positioning systems capable of providing necessary navigational information, nearly all large scale marine magnetic surveys are performed by airborne methods.

In extremely shallow water situations, magnetic surveying can be performed walking the instrument along grid lines just as if it where a land survey. Also, several somewhat waterproof coil head or magnetic metal detectors can be utilized to identify submerged iron objects.

The usage of ground penetrating radar in shallow freshwater to approximate depths of 25 feet (7.6 meters), is possible. Since freshwater generally exhibits a low conductivity, radar energy will penetrate freshwater to various depths, dependent upon antenna frequency. Also, dependent upon the electrical characteristics of the bottom sediments, sub bottom penetration may be observed. The survey profiling is often performed by placing the antenna on the floor of an inflatable raft. Pulling or towing the raft across the water body on a grid system is possible. The application of freshwater radar to engineering related bridge scour surveys, location of submerged military targets and as a method of counting fish are recent innovative instrument utilizations. The penetration capabilities of radar in the freshwater environment offers the archaeologist an excellent exploratory method for investigating submerged sites. To date, its usage for such work has not been reported. A figure provided in Appendix D exhibits a recent radar profile acquired in 1 to 10 feet (0.3-3.0 meters) of water for observation of bridge scour phenomena.

6.0 Geophysical Methods Having Limited Archaeological Applications

Previous discussions have concerned those geophysical methods believed to be most useful for archaeological investigations. Cursory familiarization with several other available surveying methods is worthwhile for those extremely specialized cases. The order of presentation and discussion length indicate the perceived usefulness for archaeological purposes.

6.1 Acoustic Surveys: Informative Discussion

6.1.1 Seismic Reflection and Refraction Methods

The seismic method involves the gathering of high resolution acoustic refraction or reflective data. The data collected, when computer processed and interpreted correctly, can be used to define natural geologic conditions including thickness and depth of soil and rock layers, their physical properties and composition, and depth to the water table or bedrock. Additionally, high resolution seismic methods sometimes allows for the detection of anomalous features, such as pits and trenches, and for evaluation of the depth of burial sites or landfills.

The transmission of seismic (acoustic) waves in the subsurface are dependent upon soil and rock lithologies. Velocities of the seismic waves change as they are reflected and refracted at interfaces between lithologic layers. These changes affect the travel path of the waves and consequently determine the travel times of the seismic waves through the rock or soil medium. Soil and rock materials may exhibit acoustic velocities of 500-25000 ft./sec. (150-7575 m/sec.) and are primarily dependent upon density properties. Often, the velocities observed for many rock types overlap, providing non-unique interpretative solutions.

The generation of a source wave and the subsequent detection of the transmitted wave by an array of geophones, laid out on the surface allows, for a travel time measurement. This time signal measurement is displayed and recorded on a seismographic instrument. The interpretation of this data allows for the resolution of the hydrogeologic subsurface conditions beneath the study area.

The seismograph is an instrument which electronically amplifies and displays the received seismic signal from the geophone. The displayed information may be on a cathode ray tube, strip chart, photographic paper or magnetic tape. The measurement and identification of the arrival times at each geophone location of the reflected or refracted acoustic wave from the seismic source is obtained from this presentation. The time is measured in milliseconds, with zero time or start of trace initiated by the source, providing a trigger signal to the seismograph.

The seismic line is centered over the study area and overall length is usually three to five times the maximum depth of interest. Resolution of the data collected is determined by the geophone spacing, shot location, the number of active seismograph channels and the signal sampling rate of the instruments. Close geophone spacings and shot intervals are required for high resolution of shallow geologic sections. Travel time may be plotted against source to geophone distances producing a time/distance plot. Computer processing is necessary to enhance the collected seismic data by noise cancellation and data stacking techniques such that a representative synthetic geologic cross section can be produced. This section is useful in determining the location of geologic anomalies, man-made features, placement of monitoring core hole and reclamation devices.

The depth of subsurface investigation of the seismic method can be varied drastically. The placement of the geophones on the surface, characteristics of the energy source and so called listening time (time spent recording the returning seismic signal) all control the depth of investigation. In many cases, penetration usually on the order of 100 feet (30.5 meters) is suitable for most site studies. In some instances, depths of several hundred to thousands of feet (meters) may be required for successful site characterization. High resolution seismic reflection methods require large expenditures in the range of $30,000 per mile ($19,000 per kilometer).

Seismic refraction techniques usually involve investigation of the shallow subsurface groundwater or bedrock interfaces and may have limited archaeological applications. Data acquisition is relatively easy, often utilizing a sledge hammer and striking plate as an acoustic source. Geophones may be placed at 10-20 foot (3-6 meter) intervals over a distance of 120-240 feet (40-60 meters) employing a twelve channel or geophone array seismograph system. Interpretation and processing of the data involves examination first arrival time acoustic signals verses distance to each geophone over the geophone array spread length. In the best circumstances a velocity can be calculated for each observed geologic layer change, subsequently allowing a useful depth of burial determination.

The cost of seismic refraction equipment is dependent upon equipment sophistication. Twelve channel exploration equipment may be purchased for $10,000-$20,000. Generally, a survey can be performed by a two man contract crew at a cost of two (2) dollars per linear foot ($6.10 per linear meter). Data interpretation often involves computer plotting and manipulation of data sets. Daily interpretation fees of $350 to $500 can be expected.

6.1.2 Shear Wave Seismic Methods

A shear wave acoustic source verses employment of a compressional acoustic source differentiates this method from normal seismic reflection or refraction surveying. It is almost exclusively utilized in soil engineering investigations to determine shear strengths of soil materials for construction purposes.

6.1.3 Acoustic Emissions

Sub audible sound waves are generated by the release of elastic strain energy within earthen structures such as dams slope embankments, and foundation walls. These sounds can be measured by an acoustic emission monitor and transducer.
A count of sound events is generally tabulated each minute. An increase in the number of events observed per unit time can be an indication of increasing structural instability.

6.2 Other Electrical/Electromagnetic Surveying Methods

A variety of other electrical/electromagnetic methods exist that are utilized for geological exploration. Several are passive techniques, while others rely on active signal transmission techniques. All provide a measure of resistivity, conductivity or some other electrically related resultant phenomena. A short description of each follows.

Induced Polarization (IP) is an active method. Application of an electrical current into the subsurface is used to determine electrical and polarization properties of materials. It is similar to resistivity methods. A measurement of the capacity of the subsurface to be electrically charged or polarized with respect to time, frequency, and phase shift is observed. The time duration to return to a natural or neutral state after cessation of the electrical charge measures a characteristic physical property. Also, the over voltage required to achieve charging or polarization can be measured. Experimentation with IP for archaeological investigations has been performed in the 1970's. Equipment requirements, interpretive processes, and survey time allocations limited its application to site investigations.

Magnetotellurics (MT) is both a passive (MT) and (controlled source, CSMT) active geophysical method. It provides a measurement of resistivity and phase or apparent impedance of subsurface materials. It is useful in geologic basin analysis and geothermal exploration.

Very Low Frequency (VLF) radio transmissions from various world wide military installations provide a source. The instrument detects anomalous vertical magnetic field components caused by source signal interaction with subsurface conductors. It is primarily utilized for geologic reconnaissance. VLF instruments can provide information pertaining to approximate location and type of conductors in the subsurface to depths of 200-300 feet (66-98 meters).

Time Domain Electromagnetic Method (TDEM) is an active method. The method provides a sample of the decay curve produced in a receiving coil by resultant eddy currents in the subsurface. It provides a measurement of electrical conductivity, for identification of mineralization, shear zones, zones of brine or salt water, waste contamination and surficial conductors.

6.3 Borehole and Tomographic Surveying

Exploration for hydrocarbons is the major impetus in the development of borehole geophysical methods. With the development of resistivity surveying tool by the French in the 1920's, and more recently development of borehole radar instruments, all classical, as well as, non classical methods have been adopted to borehole investigations. To date, these methods have not only been utilized in mineral exploration, but are finding widespread usage in the environmental and engineering sectors. Since borehole investigations are generally related to and have been developed for deeper geologic investigations, its usefulness in shallow archaeological investigations is very limited. One significant usage of borehole techniques, which may have some significance to archaeology, has been the radar and acoustic tomographic studies performed to locate tunnels and subsurface voids. Tomographic geophysical investigations, likened to a medical Cat scan, are performed from borehole to surface or borehole to borehole. This investigative method can provide a cross sectional image of the subsurface material between boreholes. Borehole tomography is a recent geophysical development, Method development and resultant increases in subsurface resolution may offer the archaeologist an important, new subsurface investigation tool for deeply buried features.

7.0 Quality Control

7.1 Purpose

The performance of an archaeological related geophysical survey is certainly of great importance to our cultural heritage and site investigators. Comparing it to a civil engineering or hazardous waste related geophysical investigation, though, where public safety is of concern, the rigors of survey performance may be somewhat more relaxed. Nevertheless, a quality control or assurance plan should be established. It should provide a description of task objectives, prescribe acceptable methods to satisfy the objectives and offer guidelines for reporting of conclusions. A standardization of these criteria, on a project basis, will assure presented conclusions are reasonable and will survive future scrutiny.

7.2 Equipment

Electronic geophysical equipment, subject to field and travel related abuse, is prone to mechanical, electronic failures and related problems. All equipment, when supplied by the manufacturer, is calibrated to some sort of nationally or professionally accepted calibration standard. Equipment calibration divergence often occurs as instruments age, such that quality control procedures become very important. The geophysicist must address this fact of life. A knowledgeable surveyor will often perform field calibrations consisting of electronic testing of the equipment or performing test surveys against known targets. Often, total equipment failure requires calibration by the manufacture. It is often possible to continue with a survey even when the instrument is known to be out of calibration. Equipment quality control is not so much related to absolute calibration, but realization of how poor calibration may affect the survey.

7.3 Personnel

The complexity of the project should dictate the level of education and experience necessary to perform a geophysical survey. Where a single method of investigation is proposed for an archaeological site, a geophysicist specializing in that method should be considered. Where multiple surveys are scheduled, an organization providing a variety of expertise may be a good choice. Field acquisition personnel may be less experienced as long as a project manager having a proper level of experience is present.

7.4 Field Oversight

On-site project management is an important quality control requirement. Oversight individuals should include the geophysical project manager and the principal site investigator. While in the field these individuals will provide an ongoing assessment of operations to assure all project objectives are achieved.

7.5 Record Requirements

A geophysical project file will be generated over the life of the investigation. Depending upon the sophistication of the project, it may include the following:

1. Description of Project Objectives.
2. Investigation Plan.
3. Information of Other Investigations.
4. Description of Daily Activities.
5. Field Reports and Administrative Records.
6. Original Field Data with Preliminary Analyses.
7. Formal Data Analyses and Evaluations.
8. Site Maps, Geophysical Profiles and Maps.

8.0 Administrative Requirements

Project administration often requires a daily review of activities to assure that quality, as well as cost controls are maintained. This is especially important when a survey and interpretation are preferred on a cost plus basis. Typical information may include daily report of field activity, budgeting, equipment usage and time allocations.

8.1 Field Activity Records

A daily journal of field activities performed on-site, kept by the investigator or operator, is highly recommended. This may include descriptions of changes to the geophysical survey, listings of personnel and visitors to the site, and a general assessment of survey performance and progression.

8.2 Budget Reconciliation

Submission of a daily record of survey expenses may be a requirement for extended projects. Expenses related to equipment purchases and rentals, subcontractor services, such as land surveyors, subsistence requirements, equipment shipping and wages of personnel may be reported.

8.3 Equipment Usage

A log of geophysical equipment usage should be maintained. Information concerning equipment operating hours, serial numbers, calibrations performed and notation of known deficiencies and associated corrective actions are normal reporting requirements.

8.4 Time Allocations

As a final administrative function a project related time allocation log can be maintained over the survey period. Since much of the expense of a survey is primarily labor related, this is an excellent method of determining proper utilization of manpower. Adherence to a predetermined survey schedule is often a difficult task, even in the best of circumstances. Tracking of time expenditures will indicate survey problem areas requiring corrective actions.

9.0 Acquisition Records

9.1 Original Data Sets

Knowledgeable archaeological investigators are very familiar with time, effort and expense required to conduct field operations. Geophysical operations are performed under similar circumstances. Since much of the acquired geophysical field data is unique, it must be considered irreplaceable since budgets and time constraints are often limited.

All hard copy data including field data sheets, graphic paper records, as produced in seismic and ground penetrating radar surveys, observer field notes, supporting information and data listings as acquired in a magnetic or terrain conductivity survey should be appropriately labeled, catalogued and stored carefully. Misplacement or loss of even a small portion of data information can render an entire survey useless. As an example, if one magnetic profile line is dropped from a grid survey and not accounted for, inaccurate anomaly location will occur, from that point onward. Excavation on a poorly located feature may discredit the use of geophysical methods on that site in the future.

As a precaution, copying of all data sets should be performed as soon as possible. This can be done in the field for computer listings, if a printer is available, or upon return to the office. Reproduction of certain graphic records such as graphic GPR data, is well worth the expense. If original data is to be forwarded, a transmittal letter should accompany the information.

9.2 Data Storage

Upon project completion, either the archaeological investigator or the geophysical contractor should store the data for an appropriate time period, usually over the duration of the project. Often graphic paper outputs will deteriorate over time and may require special handling. Even magnetic tapes when stored under ideal conditions will skew, possibility losing bits of information. If storage requirements are to be lengthy, transfer to computer optical disk or reproducible film is highly recommended. This information should be appropriately catalogued for future reference.

10.0 Project Planning Requirements

A compilation of project planning guidelines follows. Before a survey is to be attempted or contractor bids are sought, archaeological investigators should possess a working knowledge of these factors.

10.1 Overall Statement of Project Objectives: Task Definition

- Review of available site information to provide a descriptive assessment of site:

    Surface: location, area extent, access, climate.
    Subsurface: soil type, ground water, geology.

- Consideration of Site Specific Conditions:

    Cultural: sources of geophysical noise.
    Vegetation and other surface obstructions.
    Site access clearances, ownership.
    Insurance Requirements.
    Coordination of investigator activities.
    Time constraints.

- Integration of Additional Investigations:

    Geophysical.
    Excavation.
    Aerial Surveys.

- Probability of Success:

    Target size and depth.
    Survey method accuracy.
    Proposed survey methods and survey locations.
    Quality assurance definition.

10.2 Formulation of the Survey Plan: Getting Started

Whether the geophysical survey is to be performed by a contractor or by the archaeological investigators, a preliminary survey plan is required. If a well thought out plan is supplied to the contractor, it will indicate the archaeologist is familiar with geophysical methods. Thus, much of the superfluous communication can be eliminated from the contractor's proposal. Elements of the plan should address the following:

- Previews of proposed operations and scheduling.

- Provision for a base map, plot plan or air photos.
- Proposed survey configuration.
- Establishment of surface locating requirements.
- Requirements for equipment and procedural checks.
- Data acquisition and survey adjustment discussion.
- Data reduction: field and office requirements.
- Quality assurance and inspection.
- Presentation of findings, upon survey completion.

11.0 Technical Review

The ability to technically review the correctness of a geophysical survey requires education and experience. In the archaeological context however, ground truthing will more likely determine, at least in the archaeologist's mind, survey technical merits.

The technical review should be performed on a total project basis. Review of the proposal should indicate a clear understanding of: project objectives, tasks required to satisfy the objectives and desired results. Field data and procedures are reviewed for quality, documentation and calibration requirements. Interpretational review includes observation of acceptable data reduction techniques, computational accuracy, and integration of pertinent information. The final report should be reviewed for professionalism, accuracy and presentation of clearly understandable objectives, equipment and procedural descriptions, findings and recommendations.

12.0 Concluding Remarks: The Perfect Survey

From the point of view of the geophysicist, the requirements for a perfect survey would consist of:

1. The Client: providing an absolutely clear understanding of desired results.
2. The Site: low noise, high contrast targets, and easy access.
3. Acquisition: the ability to acquire unlimited data sets utilizing all site-applicable methods.
4. Ground Truth: an instant capability to excavate all detected anomalies.
5. Time: sufficient allocation of interpretive time to analyze all data consequences, plus two weeks.

Reality dictates that these are highly unlikely occurrences. On occasion, a site or project may exhibit one of these luxuries but rarely two or more.

The presentation of these methods applicable to archaeological investigations will hopefully enlighten interested individuals. Understanding the capabilities and complexities of geophysical surveying can only be realized by having access to geophysical equipment and working with a knowledgeable geophysicist.

Appendix A:

Glossary of Terms

A

ACCELEROMETER - A geophone whose output is proportional to acceleration. A moving coil geophone, for example, with a response proportional to frequency (as may be the case below the natural frequency) may operate as an accelerometer.

ACOUSTIC LOGGING - A borehole logging survey which will display any of several aspects of acoustic-wave propagation, i.e., a sonic, amplitude, character or 3-D log.

AMPLITUDE - The size of a signal, either in the ground or after amplification. Usually measured from the zero or rest position to a maximum excursion. The amplitude of a signal has units based on velocity (in/sec) or displacement (in).

ANALOG - (1) A continuous physical variable (such as voltage or rotation) which bears a direct linear relationship to another variable (such as earth motion) so that one is proportional to the other. (2) Continuous as opposed to discrete or digital.

ANOMALY - A deviation from uniformity in physical properties, often or exploration interest. For example, a travel time anomaly, Bouger anomaly, free-air anomaly.

APPARENT VELOCITY - (1) The velocity with which a wavefront registers on a line of geophones. (2) The inverse slope of a time-distance curve.

ARCHAEOGEOPHYSICS - Prospection in European terms, usage of geophysical methods to evaluate an archaeological site.

B

BASEMENT - (1) Complex, generally of igneous and metamorphic rocks overlain unconformably by sedimentary strata. (2) Crustal layer beneath a sedimentary layer and above the Mohorovicic discontinuity.

BEDROCK - A solid rock exposed at the surface of the earth or overlain by unconsolidated material.

BLIND ZONE - Hidden layer, normally associated with refraction seismic.

C

CABLE - The assembly of electrical conductors used to connect the geophone groups to the recording instruments.

CASING - Tubes or pipes used to line drill holes or shotholes to keep them from caving in. Usually made in ten-foot lengths which screw together.

CATHODIC PROTECTION - Electrical corrosion protection for pile foundations, electrical grounding mats, buried pipelines, etc., generally requiring soil and rock electrical resistivity measurement. Can have a detrimental affect on electrical and electromagnetic surveys.

CHANNEL - (1) A single series of interconnected devices through which geophysical data can flow from sources to recorder. Most seismic systems are 24 channel, allowing the simultaneous recording of energy from 24 groups of geophones. (2) A localized elongated geological feature resulting from present or past drainage or water action; often presents a weathering problem. (3) An allocated portion of the radio-frequency spectrum.

CHARACTER - (1) The recognizable aspect of a seismic event, usually in the waveform, which distinguishes it from other events. Usually a frequency or phasing effect, often not defined precisely and hence dependent upon subjective judgment. (2) A single letter, numeral, or special symbol in a processing system. See also byte, with which it is sometimes used interchangeable.

COMMON DEPTH POINT (CDP) - The situation where the same portion of subsurface produces reflections at different offset distances on several profiles. Related to seismic reflection surveying.

COMPRESSIONAL WAVE - A elastic body wave in which particle motion is in the direction of propagation. (Same as P-waves, longitudinal wave, dilation wave).

COULOMB'S LAW - Law of magnetic attraction which relates a force between two magnetic poles separated by some distance.

CRITICAL ANGLE - Angle of incidence, for which the refracted ray grazes the surface of contact between two media (of velocities) V1 and V2):

$$\sin = V1/V2$$

CRITICAL DISTANCE - Used in either of two different meanings; (1) The offset at which a refracted event becomes the first break; cross-over distance. (2) The offset at which the reflection time equals the refraction time; that is, the offset for which the reflection occurs at the critical angle. Important aspect of seismic refraction surveying.

CROSSFEED (Crosstalk) - Electrical or acoustic interference resulting from the unintentional pickup of information or noise on one channel from another.

CROSS-SECTION - A plot of seismic or GPR events, similar to a geologic section.

D

DATUM - (1) The arbitrary reference level to which measurements are corrected. (2) The surface from which seismic reflection times or depths are measured, corrections having been made for local topographic and/or weathering variations. (3) The reference level for elevation measurements, often sea level.

DELAY TIME - (1) In refraction work, the additional time taken for a wave to follow a trajectory to and along a buried marker over that which would have been taken to follow the same marker considered hypothetically to be at the ground surface or at a reference level. Normally, delay time exists separately under a source and under a detector; and is dependent upon the depth of the marker at wave incidence and emergence points. Shot delay time plus geophone delay time equals intercept time. (2) Delay produced by a filter.

DIFFRACTION - (1) Scattered energy which emanates from an abrupt irregularity of rock type, particularly common where faults cut reflecting interfaces. The diffracted energy shows greater curvature than a reflection (except in certain cases where there are buried foci), although not necessarily as much as the curve of maximum convexity. It frequently blends with a reflection and obscures the fault location or becomes confused with dip. (2) Interference produced by scattering at edges. (3) The phenomenon by which energy is transmitted laterally along a wave crest. When a portion of a wave train is interrupted by a barrier, diffraction allows waves to propagate into the region of the barrier's geometric shadow.

DIGITAL - Representation of quantities in discrete units. An analog system is one in which the information is represented as a continuous flow of the quantity constituting the signal.

DIPOLE - A pair of closely spaced current electrodes which approximates a dipole field from a distant pair of voltage detecting electrodes.

E

ELASTIC CONSTANTS: Important seismic surveying relationships.

(1) Bulk modulus, K - The stress-strain ratio under hydrostatic pressure:

$$K = \frac{\Delta P}{\Delta V/V}$$

where P = pressure change, V = volume, and Δ V = change in volume.

(2) Shear modulus = rigidity modulus = Lame's constant, μ - The stress-strain ratio for simple shear:

$$\mu = \frac{\Delta F/A}{\Delta L/L}$$

Where Δ F = the tangential force, A = cross-sectional area, L = distance between shear planes, and Δ L = shear displacement. The shear modulus can also be expressed in terms of other moduli as:

$$\mu = ½ E/(1 + \sigma)$$

(3) Young's modulus = stretch modulus, E - The stress-strain ratio when a rod is pulled or compressed:

$$E = \frac{\Delta F/A}{\Delta L/L}$$

where Δ F/A = stress force per unit area, L = original length and Δ L = change in length.

(4) Lame's λ constant - If a cube is stretched in the up-direction by a tensile stress, S, giving an upward strain, s, and S' is the lateral tensile stress needed to prevent lateral contraction, then:

$$\lambda = S'/s$$

This constant can also be expressed in terms of Young's modulus, E, and Poisson's ratio, σ:

$$\lambda = \frac{\sigma E}{(1 + \sigma)(1 - 2\sigma)}$$

ELECTROMAGNETIC - Periodically varying electromagnetic fields, such as light, radio waves, radar, etc.

F

FILTER - (1) The part of a system which discriminates against some of the information entering it. The discrimination is usually on the basis of frequency, although other bases such as wavelength or moveout (see velocity filter) may be used. The act of filtering is called convolution. (2) Filters may be characterized by their impulse response or more usually be their amplitude and phase response as a function of frequency. (3) Bandpass filters are component filters. (4) Notch filters reject sharply at a particular frequency. Primarily used to reject 60Hz line noise. (5) Digital filters provide a means of filtering data numerically in the time domain by summing weighted samples at a series of successive time increments. Digital filtering can be the exact equivalent of electrical filtering. Digital filtering is very versatile and permits one to filter easily in accordance with arbitrarily chosen characteristics which might prove very difficult or impossible to introduce with electrical components.

FIRST BREAK - First arrival - The first recorded signal attributable to seismic wave travel from a known source. First breaks on reflection records are used for information about the weathering. Refraction work is based principally on the first breaks, although secondary (later) refraction arrivals are also used.

FREQUENCY - The repetition rate of a periodic waveform measured in cycles per second or Hertz. Angular frequency measured in radians per second.

G

GAL- An acceleration of one centimeter per second related to gravity. A milligal is 0.001 gal.

GAMMA- Common unit of magnetic intensity, equal to 0.00001 oersted, where an oersted is a unit of magnetic intensity.

GEOPHONE - (SEISMOMETER, JUG) Instrument used to convert seismic energy into electrical energy.

GEOPHONE STATION - Point of location of a geophone on a spread, expressed in engineering notation as 1+75 taken from 0+00 at the beginning of the line.

GRAVIMETER - gravity meter - An instrument for measuring variations in gravitational attraction.

GRAVITY SURVEY - A survey performed to measure the gravitational field, or derivatives, to associate differences in the field with density distribution and therefore differences in rock types.

H

HIDDEN LAYER - A layer which cannot be detected by refraction methods, typically a low velocity layer lying beneath a high velocity layer.

HYDROPHONE - Pressure detector - A detector sensitive to variations in pressure, as opposed to a geophone which is sensitive to motion. Used when the detector can be placed below a few feet of water as in marine or marsh work or as a well seismometer. The frequency response of the hydrophone plant depends on its depth beneath the surface because of a standing wave pattern subject to the boundary condition that pressure be zero at the surface and a maximum at a quarter wave length.

I

IN-LINE OFFSET - Shotpoints that are in line, but offset to, a spread.

L

LEADS - An electrical conductor used to connect electrical devised. Geophones are connected to cables at the takeouts via leads on the geophones.

LINE - A series of profiles shot in line.

LOW-VELOCITY LAYER (LVL) - weathering. The surface layer which exhibits low seismic velocity.

M

MAGNETIC SURVEY - A Survey performed to measure the magnetic field, or its components as a means of locating concentrations of magnetic materials or determining depth to basement.

MILLIMHO - unit of measurement of conductivity, the inverse of resistivity or electrical resistance, ohm.

MILLISECOND - a time interval of one thousandth (0.001) of a second, most often related to seismic data.

MILLIVOLT - one thousandth (0.001) of a volt. Volt is a unit measurement of electromotive force.

MIS-TIE - (1) The time difference obtained on carrying a reflection event or some other measured quantity around a loop; or the difference of the values at identical points on intersecting lines or loops. (2) In refraction shooting, the time difference from reversed profiles which given erroneous depth and dip calculations.

N

NANOSECOND (ns) - One billionth of a second, unit of measurement often utilized in ground penetrating radar to describe depth of penetration into the subsurface.

NANOTESLA (nT) - Unit of magnetic anomaly magnitude, equivalent to 1 gamma.

NEWTON'S LAW - Law of gravitation, which expresses a force of attraction between two masses.

NOISE - (1) Any undesired signal; a disturbance which does not represent any part of a message from a specified source. (2) Sometimes restricted to energy which is random. (3) Seismic energy which is not resolvable as reflections. In this sense noise includes microseisms, shot-generated noise, tape-modulation noise, harmonic distortions, etc. Sometimes divided into coherent noise (including non-reflection coherent events) and random noise (including wind noise, instrument noise, and all other energy which is non-coherent), to the extent that noise is random, it can be attenuated by a factor of $\sqrt{n}$ by compositing n signals from independent measurements. (4) Sometimes restricted to seismic energy not derived from the shot explosion. (5) Disturbances in observed data due to more or less random inhomogeneities in surface and near-surface materials.

NOISE SURVEY - Or ground noise survey. A mapping of ambient, continuous seismic noise levels within a given frequency band. As some geothermal reservoirs are a source of short-period seismic energy, this technique is a useful tool for detecting such reservoirs.

O

OBSERVER - The geophysicist in charge of recording and overall field operations on a seismic crew.

OHM - Unit of electrical resistance.

ON-LINE - Shotpoints that are shot at any point on a spread other than at the ends of the spread.

ORIGINAL DATA - Any element of data generated directly in the field in the investigation of a site; or a new element of data resulting from a direct manipulation or compilation of the field data.

OSCILLOGRAPH - Camera.

OSCILLOSCOPE - A type of oscillograph that visually displays an electrical wave on a fluorescent screen, as of the cathode ray tube type.

P

PLANT - The manner in which a geophone or electrode is placed on or in the earth; the coupling to the ground.

PRIMACORD - An explosive rope that can be used to either connect explosive charges, or can be detonated separately as a primary energy source.

PROFILE - The series of measurements made from several shotpoints into a recording spread, from which a seismic data cross section or profile can be constructed.

PROSPECTION - European term for archaeogeophysics, or the usage of geophysical methods for archaeological assessments.

PVC - Polyvinylchloride, a plastic tubing or pipe that is used to case corings or shotholes.

R

RADAR - A system in which short electromagnetic waves are transmitted into a medium, and the energy which is scattered back by reflecting objects is detected. May be used for shallow penetration surveys in the ground, salt, ice, fresh water, masonry and other materials.

RAYLEIGH WAVE - A seismic wave propagated along a free surface. The particle motion is elliptical and retrograde.

RAYPATH - A line everywhere perpendicular to wavefronts (in isotopic media). The path which a seismic wave takes.

RECONNAISSANCE - (1) A general examination of a region to determine its main features, usually preliminary to a more detailed survey. (2) A survey whose objective is to ascertain regional geological structures or to determine whether economically prospective features exist, rather than to map an individual structure.

REFLECTION SURVEY - A survey map of geologic structure using measurements made of arrival time of events attributed to seismic waves which have been reflected from interfaces where the acoustic impedance changes.

REFRACTION SURVEY - A survey to map geologic structure and to determine compressional wave velocities by using head waves. Head waves involve energy which enters a high-velocity medium (refractor).

REFRACTION WAVE - Head wave - Mintrop wave - conical wave - wave travel from a point source obliquely downward to and along a relatively high velocity formation or marker and thence obliquely upward. Snell's law is obeyed throughout the trajectory. Angles of incidence and of emergence at the marker are critical angles. Typically, refracted waves following successively deeper markers appear as first arrivals with increasing range (shot to detector distance). Refracted waves following different markers may occur at different arrival times for any given range. Such waves cannot arise for angles of incidence less than the critical angle for any given marker. At the critical angle, the refracted wave path (and its travel time) coincides with that of a wide angle reflection.

REFRACTOR - Refraction marker: A relatively high velocity extensive layer, underlying lower velocity layers, which transmits a refraction wave horizontally.

RESISTIVITY - (electrical) - A property of rock material giving a measure of the difficulty involved in driving an electrical current through it. Mathematically, resistivity is the ratio of electric field intensity to current density.

RESISTIVITY METER - A general term for an instrument used to measure in situ the resistivity of soil and rock materials.

RESISTIVITY SURVEY - A survey performed to observe the electric fields and earth resistivity caused by introducing a current into the ground.

REVERSE PROFILE - A refraction seismic profile that has been generated by shooting at both ends of a spread.

S

SEISMIC AMPLIFIER - An electronic device used to increase the electrical amplitude of a seismic signal. (see geophone)

SEISMIC CAMERA - A recording oscillograph used to produce a visible pattern of electrical signals to make a seismic record.

SEISMIC CAP - A small explosive designed to be detonated by an electrical current, which in turn detonates another explosive. These caps are designed to provide very accurate time control on the shot instant.

(SEISMIC) VELOCITY - The rate of propagation of seismic wave through a medium.

SEISMOGRAM - A seismic record.

SELF POTENTIAL - Spontaneous potential, natural potential, SP. The dc or slowly varying natural ground voltage between nearby, non-polarizing electrodes.

SHEAR WAVE - A body wave in which the particle motion is perpendicular to the direction of propagation. (Same as S-wave, equivoluminal, transverse wave).

SHOTPOINT - Point of location of the energy source used in generating a particular seismogram. Expressed either sequentially for a line (i.e., SP-3) or in engineering notation (i.e., SP 3+00).

SIGNAL ENHANCEMENT - A hardware development utilized in seismographs and resistivity systems to improve signal-to-noise ratio by real-time adding (stacking) successive waveforms from the same source point and thereby discriminating against random noise.

SITE DATA PACKAGE - Accumulation of geophysical data information from a single source of dissemination analysis and evaluation against the site criteria. Would include: charts, records, field notes, maps, photographs, technical reports, lab reports. etc.

SNELL'S LAW - When a wave crosses a boundary between two isotropic mediums, the wave changes direction such that the sine of the angle of incidence of the wave divided by the velocity of the wave in the first medium equals the sine of the angle of refraction of the wave in the second medium divided by the velocity of the wave in the second medium (see critical angle).

SPREAD - The layout of geophone groups from which data from a single shot are recorded simultaneously.

T

TELLURIC - Pertaining to the earth.

TRACE - A record of one seismic channel. This channel may contain one or more geophones. A trace is made by a galvanometer.

V

VELOCITY - Quickness of motion, rate of motion through some media, such as the earth.

VIBROSEIS - A seismic energy source consisting of controlled frequency input into the earth by way of large vibrators (truck mounted).

W

WAVE LENGTH - The distance between successive similar points on two adjacent cycles of a wave, measured perpendicular to the wavefront. Expresses as = v/f, where = wavelength, v = wave velocity and f = wave frequency.

WWV - The U. S. Bureau of Standards radio station that broadcasts time and frequency standards.

* * * * *

For the definition of other geophysical terms used in this manual, refer to: Glossary of Terms Used in Geophysical Exploration, Society of Exploration Geophysicists, Tulsa, Oklahoma, 1984.

Appendix B:

Selected Bibliography

1. GENERAL WORKS

Aitken, M.J.
1974 Physics and Archaeology. 2nd Edition. Clarendon Press, Oxford, England.

Arnold III, J.B.
1982 Archaeological Applications of Computer Graphics. In Advances in Archaeological Method and Theory, vol. 5, edited by M.B. Schiffer, pp. 179-216. Academic Press, New York.

Atkinson, R.J.C.
1953 Field Archaeology. 2nd. Edition. Methuen, London.

Barnes, H.E.
1952 Mapping and Subsurface Exploration for Engineering Purposes. In Michigan State Highway Department Research Board Bulletin 65.

Battelle Pacific Northwest Laboratories
1981 Computer-enhanced Geophysical Survey Techniques for Location of Underground Objects and Structures. Report by Battelle Pacific Northwest Laboratories, Richland, Washington.

Baugh, T.G.
1982 Edwards I (34BK2): Southern Plains Adaptations in the Protohistoric Period. Studies in Oklahoma's Past, No. 8. Oklahoma Archeological Survey, Norman.

Bevan, B., and J. Weymouth (editors)
1982 A Compendium of Recent Geophysical Surveys. Society for Archaeological Sciences Newsletter 6(11):3-4.
1984 Recent Geophysical Surveys of Archaeological Sites. Society for Archaeological Sciences Newsletter 7(3):4-6.

Bray, D.E., and R.K. Stanley
1989 Nondestructive Evaluation. McGraw-Hill Book Co., New York.

Brothwell, D., and E. Higgs (Editors)
1969 Science in Archaeology. 2nd Edition. Thames and Hudson, London.

Black, G.A., and R.B. Johnston.

1962 A Test of Magnetometry as a Aid to Archaeology. American Antiquity 28:199-205.

Clark, A.

1975 Archaeological Prospecting: A Progress Report. Journal of Archaeological Science 2(4):297-314.

1990 Seeing Beneath the Soil: Prospecting Methods in Archaeology. B.T. Batsford Ltd, London.

Corbyn, R.

1976 Archaeological Photo Interpretation of the Deer Creek site. Unpublished master's thesis, Department of Anthropology, Pennsylvania State University, University Park.

Davis, J.C.

1973 Statistics and Data Analysis in Geology. Wiley, New York.

Davenport, G.C. and L. Hadley

1986 Exploration Geophysics, Chapter 6. Engineering Geology Handbook. U.S. Bureau of Reclamation, Denver, Colorado.

Davenport, G.C. and S.L. De Vore

1991 Geophysical Techniques in Archaeology, Pinon Canyon Maneuver Site, Colorado Workshop. Interagency Archaeological Services, Rocky Mountain Regional Office, National Park Service, Denver, Colorado.

Davenport, G.C., T.J. Griffin, J.W. Lindemann, and D.Heimmer

1990 Geoscientists and Law Officers Work Together in Colorado. Geotimes 35(7):13-15.

De Vore, S.L., W.C. Brennan, and T.M. Deignan

1992 Geophysical Applications in Archaeology: A Case Study at the Twelve Mile House (5AH121), Arapahoe County, Colorado. Southwestern Lore 58(1):1-16.

Dobrin, M.B., and Savit, C.H.

1988 Introduction to Geophysical Prospecting. 4th Edition. McGraw-Hill, New York.

Dolphin, L.

1981 Geophysical Methods for Surveying in Israel. Report, SRI International, Menlo Park, California.

Dolphin, L.T., A.H. Moussa, and G. Mokhtar

1977 Applications of Modern Sensing Techniques to Egyptology. Prepared for the National Science Foundation by SRI International, Menlo Park, California.

Drury, S.A.

1987 Image Interpretation in Geology. Allen & Unwin, London.

Ebert, James I.

1984 Remote Sensing Applications in Archaeology. In Advances in Archaeological Method and Theory, vol. 7, edited by M. B. Schiffer, pp. 293-362. Academic Press, New York.

Eidt, R.C.

1977 Detection and Examination of Anthrosols by Phosphate Analysis. Science 297:1327-133.

Ellis, L.

1982 Laboratory Techniques in Archaeology: A Guide to the Literature, 1920-1980. Garland Publishing, New York.

Fowler, D.D.

1982 Cultural Resources Management. In Advances in Archaeological Method and Theory, vol. 5, edited by M. B. Schiffer, pp. 1-50. Academic Press, New York.

Gumerman, G.J., and T.R. Lyons

1971 Archaeology Methodology and Remote Sensing. Science 172:126-132.

Jelks, E.B., and C.J. Ekberg

1984 Archaeological Explorations at the Laurens Site (11RP125), Randolph County, Illinois, July 1983. Midwestern Archaeological Research Center, Illinois State University, Normal.

Kelly, M.A., P. Dale, and J.G.B. Haigh

1984 A Microcomputer System for Data Logging in Geophysical Surveying. Archaeometry 26(2):183-191.

Killam, E.W.

1990 The Detection of Human Remains. Charles C Thomas, Springfield, Illinois.

Leith, C.J., K.A. Schneider, and C. Carr

1976 Geophysical Investigation of Archaeological Sites. Bulletin of the International Association of Engineering Geology, No. 14.

Limbrey, S.
1975 Soil Science in Archaeology. Academic Press, New York.

Linington, R.E.
1963 The Application of Geophysics to Archaeology. American Scientist 51(1):48-70.

Lyons, T. R., and R. K. Hitchcock (editors)
1977 Aerial Remote Sensing Techniques in Archaeology. Chaco Center Reports 2. National Park Service, Albuquerque, New Mexico.

McManamon, Francis P.
1984 Discovering Sites Unseen. In Advances in Archaeological Method and Theory, vol. 7, edited by M. B. Schiffer, pp. 223-292. Academic Press, New York.

Minnerly, W.L. (editor)
1981 Oral, Historical, Documentary, and Archaeological Investigation of Colbert, Barton, and Vinton, Mississippi: An Interim Report on Phase I of the Tombigbee Historic Townsite Project. Report submitted to the Interagency Archaeological Services.

Northwest Mining Association
1989 Practical Geophysics for the Exploration Geologist 1989. Short Course, Spokane, Washington.

Parasnis, D.S.
1979 Principles of Applied Geophysics. 3rd Edition. Wiley, New York.

Parrington, M.
1979 Geophysical and Aerial Prospecting Techniques at Valley Forge National Historic Park, Pennsylvania. Journal of Field Archaeology 6(2):193-201.

Plog, S., F. Plog, and W. Wait
1978 Decision Making in Modern Surveys. In Advances in Archaeological Method and Theory, vol. 1, edited by M. B. Schiffer, pp. 383-421. Academic Press, New York.

Rainey, F.G., and E.K. Ralph
1966 Archaeology and Its New Technology. Science 153(3743):1481-1491.

Roosevelt, A.C.
1991 Moundbuilders of the Amazon, Geophysical Archaeology of Marajo Island, Brazil. Academic Press, San Diego, California.

Scollar, I.

1990 Archaeological Prospecting and Remote Sensing. Cambridge University Press, Cambridge.

Sendlein, L.V.A., and H. Yazicigil

1981 Surface Geophysical Methods for Ground Water Monitoring. Ground Water Monitoring Review 1:42-46.

Sharma, P.V.

1976 Geophysical Methods in Geology. Elsevier, New York.

Sittig, M.

1980 Geophysical and Geochemical Techniques for Exploration of Hydrocarbons and Minerals. Noyes Data Corporation, Park Ridge, New Jersey.

Szekielda, K.

1988 Satellite Monitoring of the Earth. John Wiley & Sons, Inc., New York.

Tite, M.S.

1972 Methods of Physical Examination in Archaeology. Academic Press, New York.

Ward, S.H.

1990 Geotechnical and Environmental Geophysics, Vol. 1, Review and Tutorial. Society of Exploration Geophysicists, Tulsa, Oklahoma.

Wedel, M.M.

1981 The Deer Creek Site, Oklahoma: A Wichita Village Sometimes Called Ferdinandina, an Ethnohistorian's View. Series in Anthropology No. 5. Oklahoma Historical Society, Oklahoma City.

Weymouth, J.W.

1986 Geophysical Methods of Archaeological Site Surveying. In Advances in Archaeological Method and Theory, vol. 9, edited by M. B. Schiffer, pp. 311-391. Academic Press, Orlando, Florida.

Weymouth, J.W., and R. Huggins

1985 Geophysical Surveying of Archaeological Sites. In Archaeological Geology, edited by G. Rapp and J. Gifford. Yale University Press, New Haven.

Wingfield, A., L. Pavlish, R. O'Brien, and R. Farquhar

1983 Prospection on Historic Sites in the Toronto Area: Three Surveys. Paper presented at the International Archaeometry Symposium, Naples.

Wood, W.R., R.K. Nickel, and D.E. Griffin
1984 Remote Sensing: The American Great Plains. Supplement No.9 to Remote Sensing: a Handbook for Archaeologists and Cultural Resource Managers, edited by T.R. Lyone and T.E. Avery. National Park Service, U. S. Dept. of the Interior, Washington, D.C.

Wynn, J.C.
1986 Review of Geophysical Methods Used in Archaeology. Geoarchaeology 1(3):245-257.

2. MAGNETICS

Barrows, L., and J.E. Rocchio
1990 Magnetic Surveying for Buried Metallic Objects. Ground Water Monitoring Review, Summer 1990, pp. 204-209.

Bennett, C.B., and J.W. Weymouth
1982 Magnetic Reconnaissance Program in the Dolores Archaeological Project-Interpretation of Data Collected During the Field Season 1980. Report submitted to the Dolores Archaeological Program, University of Colorado.

Black, G.A., and R.B. Johnston
1962 A Test of Magnetometry as a Aid to Archaeology. American Antiquity 28:199-205.

Breiner, S.
1973 Applications Manual for Portable Magnetometers. Geometrics, Sunnyvale, California.

Briener, S., and M.D. Coe
1972 Magnetic Exploration of the Olmec Civilization. American Scientist 60(5):566-575.

Burns, P.K.
1981 Magnetic Reconnaissance in the Dolores Archaeological Program. Unpublished master's thesis, Anthropology Department, University of Nebraska, Lincoln.

Burns, P.K., R. Huggins, and J.W. Weymouth
1983 Study of Correlation Between Magnetic Reconnaissance and Excavation in the Dolores Program. Dolores Archaeological Program Technical Reports, Report No. DAP-078. Prepared for U.S. Bureau of Reclamation, Salt Lake City, Utah.

Huggins, R.

1982 Magnetic Reconnaissance Program in the Dolores Archaeological Program: Interpretation of Data Collected During Field Years 1981 and 1982. Report submitted to the Dolores Archaeological Program, University of Colorado.

Huggins, R., and J.W. Weymouth

1981 Magnetic Reconnaissance Program in the Dolores Archaeological Program - Interpretation of Data Collected During Field Season 1979. Report submitted to the Dolores Archaeological Program, University of Colorado.

1983 Magnetometer Results. In Dolores Archaeological Program: Field Investigations and Analysis - 1978, edited by D. A. Bretevnitz, pp. 193-251. U. S. Dept. of the Interior, Bureau of Reclamation, Denver, Colorado.

Johnston, R.B.

1961 Archaeological Application of the Proton Magnetometer in Indiana (U.S.A.), Archaeometry 4:71-72.

1964 Proton Magnetometry and Its Application to Archaeology: An Evaluation at Angel Site. Indiana Historical Society Prehistorical Research Series 4(11):45-140.

Kaczor, J., and J. Weymouth

1981 Magnetic Prospecting: Preliminary Results of the 1980 Field Season at the Toltec Site, 3LN42. Southeastern Archaeological Conference Bulletin 24:118-123.

LeBorgne, E.

1965 Les Proprietes Magnetiques du Sol. Aplications a la Prospection des Sites Archeologiques. Archaeo-Physika 1:2-20.

Linington, R.E.

1972 A Summary of Simple Theory Applicable to Magnetic Prospecting in Archaeology. Prospezioni Archeologiche 7/8:9-60.

Mason, R.J.

1984 An Unorthodox Magnetic Survey of a Large Forested Historic Site. Historical Archaeology 18(2):54-63.

Morrison, F.H., C.W. Clewlow, Jr., and R.F. Heizer

1970 Magnetometer Survey of the La Venta Pyramid. Contributions of the University of California Archaeological Research Facility 8:1-20.

Ralph, E.K.

1965 Comparison of a Proton and a Rubidium Magnetometer for Archaeological Prospecting. Archaeometry 7:20-27.

Ralph, E.K., F. Morrison, and D.P. O'Brien
1968 Archaeological Surveying Utilizing a High-sensitivity Difference Magnetometer. Geoexploration 6:109-122.

Scollar, I.
1962 Electromagnetic Prospecting Methods in Archaeology. Archaeometry 5:146-153.
1969 Some Techniques for the Evaluation of Archaeological Magnetometer Surveys. World Archaeology 1:77-89.

Scollar, I., and F. Kruckebert
1966 Computer Treatment of Magnetic Measurements from Archaeological Sites. Archaeometry 9:61-70.

Steponaitis, V.P., and J.P. Brain
1976 A Portable Differential Proton Magnetometer. Journal of Field Archaeology 3:455-463.

Tabbagh, A.
1984 On the Comparison between Magnetic and Electromagnetic Prospection Methods for Magnetic Features Detection. Archaeometry 26(2):171-182.

von Frese, R.R.B.
1978 Magnetic Exploration of Historical Midwestern Archaeological Sites as Exemplified by a Survey at Fort Ouiatenon (12T9). Unpublished master's thesis, Department of Geoscience, Purdue University, West Lafayette, Indiana.
1984 Archaeomagnetic Anomalies at Midcontinental North American Archaeological Sites. Historical Archaeology 18(2):4-19.

von Frese, R.R.B., and V.E. Noble
1984 Magnetometry for Archaeological Exploration of Historical Sites. Historical Archaeology 18(2):38-53.

Weymouth, J.W.
1976 A Magnetic Survey of the Walth Bay Site. Occasional Studies in Anthropology No. 3. Midwest Archeological Center, Lincoln, Nebraska.

Weymouth, J.W., and B. Bevan
1983 Combined Magnetic and Ground Penetrating Radar Survey of an Archaeological Site in Oklahoma. Digest, Vol I, Section WP.3, International Geoscience and Remote Sensing Symposium (San Francisco). IEEE, New York.

Weymouth, J.W., and R. Huggins

1981 Final Analysis of a Magnetic Survey at the Deer Creek Site (34KA3), Kaw Lake, Oklahoma. Report submitted to the U. S. Army Corps of Engineers, Tulsa District, Tulsa, Oklahoma.

1981 Magnetic Survey of the Edwards I (34BK2) and the Taylor (34GR8) Sites in western Oklahoma. Report submitted to the Oklahoma Archaeological Survey, University of Oklahoma.

Weymouth, J.W., and R.K. Nickel

1977 A Magnetometer Survey of the Knife River Indian Villages. Plains Anthropologist 22(78:2):104-118.

Weymouth, J.W., and W.I. Woods

1984 Combined Magnetic and Chemical Surveys of Forts Kaskaskia and de Chartres I, Illinois. Historical Archaeology 18(2):20-37.

3. SELF-POTENTIAL

Corwin, R.F.

1990 The Self-Potential Method for Environmental and Engineering Applications. in Geotechnical and Environmental Geophysics, vol. 1, edited by S. H. Ward, pp 127-146. Society of Exploration Geophysics, Tulsa, Oklahoma.

Wynn, J.C., and S.I. Sherwood

1984 The Self-Potential (SP) Method: An Inexpensive Reconnaissance and Archaeological Mapping Tool. Journal of Field Archaeology 11(2):195-204.

4. GRAVITY

Guion, D.J.

1988 Gravity Prospecting in Mineral Exploration. In Practical Geophysics for the Exploration Geophysics, edited by R. Van Blaricom, pp. 153-164. Northwest Mining Association, Spokane, Washington.

Hinze, W.J.

1990 The Role of Gravity and Magnetic Methods in Engineering and Environmental Studies. In Geotechnical and Environmental Geophysics, vol. 1, edited by S.H. Ward, pp. 75-126. Society of Exploration Geophysics, Tulsa, Oklahoma.

Linington, R.E.

1966 Test Use of a Gravimeter on Etruscan Chamber Tombs at Cerveteri. Prospezioni Archaeologiche 1:37-41.

5. ELECTRICAL RESISTIVITY

Atkinson, R.F.C.
1963 Resistivity Surveying in Archaeology. In The Scientist and Archaeology, edited by E. Pyddoke, pp. 1-30. Phoenix House, London.

Bevan, B.
1991 A Resistivity Survey at the Lockwood Stage Station. Prepared for the National Park Service, Denver, Colorado.

Carr, C.
1977 A New Role and Analytical Design for the Use of Resistivity Surveying in Archaeology. Midcontinental Journal of Archaeology 2:161-193.
1982 Handbook on Soil Resistivity: Interpretation of Data From Earthen Archaeological Sites. Center for American Archaeology Press, Evanston, Illinois.

Ford, R.I., and R.O. Keslin
1969 A Resistivity Survey at the Norton Mound Group, 20KT1, Kent County, Michigan. The Michigan Archaeologist 15(3):86-92.

Hranicky, W.J.
1972 Application of Resistivity Surveying to American Archaeology. The Chesopiean 10:43-50.

Huggins, R., and J.W. Weymouth
1981 A Probe Resistivity Survey and Analysis at the Deer Creek Site(34KA3), Oklahoma. Report submitted to the U.S. Army Corps of Engineers, Tulsa District, Oklahoma.

Klasner, J.S., and P. Calengas
1981 Electrical Resistivity and Soil Studies at Orendorf Archaeological site, Illinois: A Case Study. Journal of Field Archaeology 8(2):167-174.

Tagg, G.F.
1964 Earth Resistances. Pitman, London.

Van Nostrand, R.G., and K.L. Cook
1966 Interpretation of Resistivity Data. Geological Survey Professional Paper No. 499.

6. ELECTROMAGNETIC CONDUCTIVITY

Beven, B.
1983 Electromagnetics for Mapping Buried Earth Features. Journal of Field Archaeology 10)1):47-54.

McNeill, J.D.
1980 Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers. Geonics Limited, Ontario, Canada.
1985 Operating Manual for EM31-d Non-Contacting Terrain Conductivity Meter. Geonics Limited, Mississauga, Canada.

Musson, C.R.
1968 A Geophysical Survey at South Cadbury Castle, Somerset, Using the Howell Soil Conductivity Anomaly Detector (SCM). Prospezioni Archeologiche 3:115-121.

Howell, M.
1966 A Soil Conductivity Meter. Archaeometry 9:20-23.

Parchas, C., and A. Tabbagh
1979 Simultaneous Measurements of Electrical Conductivity and Magnetic Susceptibility of the Ground in Electromagnetic Prospecting. Archaeo-Physika 10:682-691.

Tabbagh, A.
1986 Applications and Advantages of the Slingram Electromagnetic Method for Archaeological Prospecting. Geophysics 51:576-584.

Tite, M.S., and C. Mullins
1970 Electromagnetic Prospecting on Archaeological Sites Using a Soil Conductivity Meter. Archaeometry 12(1):97-104.

7. GROUND PENETRATING RADAR

Annan, A.P., Davis, J.L., and D. Gendzwill
1988 Radar sounding in Potash Mines, Saskatchewan, Canada. Geophysics 53(12): 1556-1564.

Amato, L., and G. Di Maio
1990 Ground Penetrating Radar for the Identification of Stratigraphic and Sedimentologic Features in Archaeological Investigation of the Volcanoclastic Sequence of AD 79 Vesuvian Eruption - Pompeii - Southern Italy. Third International Conference on Ground Penetrating Radar, Lakewood, Colorado.

Bevan, B., D.G. Orr, and B.S. Blades
1984 The Discovery of the Taylor house at the Petersburg National Battlefield. Historical Archaeology 18(2):64-74.

Bevan, B.

1979 A Ground Penetrating Radar Survey at the Deer Creek Site. Report prepared for the U. S. Army Corps of Engineers, Tulsa District, Tulsa, Oklahoma.

1980 A Second Season at Deer Creek: Radar and Electromagnetic Surveys. Report prepared for U.S. Army Corps of Engineers, Tulsa District, Tulsa, Oklahoma.

Bevan, B., and J. Kenyon

1975 Ground Penetrating Radar for Historical Archaeology. MASCA Newsletter 11(2):2-7.

Daniels, J.

1988 Locating Caves, Tunnels and Mines. Geophysics: The Leading Edge of Exploration, March, 1988.

1988 Fundamentals of Ground Penetrating Radar. In Symposium on the Application of Geophysics to Engineering and Environmental Problems, Golden, Colorado.

Davis, J.L., and A.P. Annan

1989 Ground Penetrating Radar for High-Resolution Mapping of Soil and Rock Stratigraphy. Geophysical Prospecting 37:531-551.

De Vore, S.L.

1990 Ground Penetrating Radar as a Tool in Archaeological Investigations: An Example from Fort Laramie National Historic Site. The Wyoming Archaeologist 33(1-2):23-38.

Fischer, P.M., S.G.W. Follin, and P. Ulriksen

1980 Subsurface Interface Radar Survey at Hala Sultan Tekke, Cyprus. Studies in Mediterranean Archaeology 62:48-62.

Fisher, E., McMechan, G.A., and A.P. Annan

1992 Acquisition and Processing of Wide-Aperture Ground Penetrating Radar Data. Geophysics 57:495-508.

Geophysical Survey Systems, Inc.

1989 Radan Instruction Manual. MN43-101 Release 3.0.

1991 Subsurface Interface Radar 10 Manual. In Press. New Salem, New Hampshire.

Heimmer, D.H., G.C. Davenport, J. Lindemann, and J. Gilmore

1989 Geophysics for Archaeological Assessment: Ft. William Discovered? Ft. Laramie National Historical Site, Wyoming. Symposium on the Application of Geophysics to Engineering and Environmental Problems, Golden, Colorado.

Imai, T., T. Sakayama, and T. Kanemori
1987 Use of Ground-probing Radar and Resistivity Surveys for Archaeological Investigations. Geophysics 52(2):137-150.

Kenyon, J.L.
1977 Ground Penetrating Radar and Its Application to a Historical Archaeological Site. Historical Archaeology 11:45-55.

Kovacs, A.
1990 Electromagnetic Sounding in the Successful Search or Buried World War II Aircraft on the Greenland Ice Cap. Third International Conference on Ground Penetrating Radar, Lakewood, Colorado.

Mellett, J., and J. Geismar
1990 GPR Survey of an African-American Cemetery in Little Ferry, NJ. Third International Conference on Ground Penetrating Radar, Lakewood, Colorado.

Michael, H.N., and R. Vickers
1979 Subsurface Radar Probing for Detection of Buried Bristlecone Pine Wood. In Radiocarbon Dating, edited by R. Berger and H. E. Suess, pp. 520-531. University of California Press, Berkely.

Olhoeft, G.R.
1988 Selected Bibliography on Ground Penetrating Radar. In Symposium on the Application of Geophysics to Engineering and Environmental Problems, Golden, Colorado.

Olhoeft, G.R.
1984 Applications and Limitations of Ground Penetrating Radar. In Expanded Abstracts, 54th Annual International Meeting and Expo., Atlanta, Georgia.

Persons, S.
1990 Burial Detection Using Ground Penetrating Radar. Third International Conference on Ground Penetrating Radar, Lakewood, Colorado.

Piccolo, M.
1990 Ground Penetrating Radar Surveys for Archaeological Purposes. Third International Conference on Ground Penetrating Radar, Lakewood, Colorado

Rossiter, J.R., J.L. Davis, and L.A. LaLumiere
1989 Review of Ground Penetrating Radar Technology. Second Annual CRL Radar Symposium, McMaster University, Hamilton, Ontario.

Sheets, P.D., W.M. Loker, H.A.W. Spetzler, R.H. Ware, and G.R. Olhoeft
1985 Geophysical Exploration for Ancient Maya Housing at Ceten, El Salvador. National Geographic Society Research Reports, In Press.

Ulriksen, C.P.
1983 Application of Impulse Radar to Civil Engineering. Geophysical Survey Systems, Hudson, New Hampshire.

Vickers, R.S., and L.T. Dolphin
1975 A Communication on an Archaeological Radar Experiment at Chaco Canyon, New Mexico. MASCA Newsletter 11(1):6-8.

8. METAL DETECTION

Carson, H.H.
1963 Detail Map and Metal Detection Survey of the Aboriginal Mine Pits, Along the Minong Ridge at McCargoe Cove, Isle Royale National Park, Michigan. Report submitted to National Park Service, Northeast Region.

Fischer, P.M.
1979 The Use of a Metal Detector in Archaeology. Opuscula Atheniensia 13:9.
1980 Geophysical Prospecting at Hala Sultan Tekke, Cyprus. Journal of Field Archaeology 7(4):479-484.

Schonstedt Instrument Company
1986 Instruction Manual Model MAC-51B Magnetic and Cable Locator. Reston, Virginia.

Scott, D.K., and R.A. Fox, Jr.
1987 Archaeological Insights into the Custer Battle: An Assessment of the 1984 Field Season. University of Oklahoma Press, Norman.

Scott, D.K., R.A. Fox, Jr., M.A. Connor, and D. Harmon
1989 Archaeological Perspectives on the Battle of the Little Bighorn. University of Oklahoma Press, Norman.

9. SIDE SCAN SONAR

Mazel, C.
1985 Side Scan Sonar Training Manual. Klein Associates, Inc., Salem, New Hampshire.

10. SEISMIC SURVEYING

Bandy, P.A. , and L. Davis
1977 "Pounding": A Useful Nondestructive Technique for Subsurface Archaeological Exploration. Paper presented at 48th Annual Meeting, Texas Archaeological Society, Arlington, Texas.

Carson, H.H.
1962 A Seismic Survey at Harpers Ferry. Archaeometry 5:119-122.

Dolphin, L.T.
1981 Geophysical Methods for Archaeological Surveys in Israel. Stanford Research International, Menlo Park, California.

Hunter, J.A., S.E. Pullen, R.A. Burns, R.M. Gagne, and R.L. Good
1988 Applications of a Shallow Seismic Reflection Method to Groundwater and Engineering Studies. Geological Survey of Canada Paper, Geological Survey of Canada, Ottawa.

Steeples, D.W., and R.D. Miller
1990 Seismic Reflection Methods Applied to Engineering, Environmental, and Groundwater Problems. In Geotechnical and Environmental Geophysics, vol 1, edited by S.H. Ward. Society of Exploration Geophysicists, Tulsa, Oklahoma.

11. BOREHOLE GEOPHYSICS

University of Arizona Laboratory for Advanced Imaging
1990 Borehole Geophysics: Petroleum, Hydrogeology, Mining and Engineering Applications. International Symposium, Department of Mining and Geological Engineering, University of Arizona, Tucson, Arizona.

12. THERMAL PROSPECTING

Benner, S.M., and R.S. Brodkey
1984 Underground Detection Using Differential Heat Analysis. Archaeometry 26(1):21-36.

Perisset M.C., and A. Tabbagh
1981 Interpretation of Thermal Prospection on Bare Soil. Archaeometry 23(2):169-187.

Appendix C:

Potential Sources of Geophysical Equipment and Surveyors

There are numerous potential sources of both free and at cost surveyors and equipment available to the knowledgeable archeologist. Knowledgeable is defined as: (1) having an ability to network with individuals involved in geophysics, (2) a good understanding of geophysical methods and their application to site assessment, (3) a good story to tell to interest the contacted individual to either lend you the equipment or help on a volunteer basis and (4) remembering anyone can rent, buy equipment or hire consultants to progress through the learning curve.

Sources of Equipment or Surveyors:

1. U. S. Governmental Agencies:
    - U. S. Geological Survey
    - U. S. Bureau of Reclamation
    - U. S. Bureau of Mines
    - EPA
2. State Agencies:
    - Geologic Surveys
    - Health and Environmental Agencies
3. Universities and Colleges:
    - Geological Departments
    - Geophysical Departments
    - Engineering Departments
4. Private and Non-Profit Organizations
5. Private concerned individuals
6. Geophysical Equipment Manufacturers
7. Geophysical Equipment Rental Companies
8. Geophysical Consultants

Access to sources 1-3 requires contacting the indicated agency within the area.

To access the other groups, it is recommended the following procedure be performed:

> Acquire a copy of the Geophysical Directory, a geophysical trade directory, published annually in March. This directory provides the most comprehensive listing of sources of equipment and individuals available. The Index page to the 1991 issue is provided for reference purposes with credits indicated.

THE GEOPHYSICAL DIRECTORY

Published Annually in March *Forty-Sixth Edition 1991*

2200 Welch Avenue P.O. Box 130508

Houston, Texas 77219

713 529-8789 *FAX: 713 529-3646*

INDEX TO CONTENTS

ADDENDUM 426
ADVERTISERS INDEX 14
AIRCRAFT SERVICES (including Helicopters and Hovercraft) 323
AUTOMOTIVE EQUIPMENT 335
AUXILIARY EQUIPMENT AND SERVICES (including Recording Cab, Winches, Generators, etc.) 315
BOATS 319
CONSULTANTS (Geophysical) 95
CORE DRILLING CONTRACTORS 128
DATA EXCHANGE SERVICE 169
DATA PROCESSING CENTERS 138
DATA PROCESSING EQUIPMENT MANUFACTURERS 177
DATA STORAGE 169
DRILLING BITS 301
DRILLING RIG BUILDERS (Geophysical) 303
ELECTRICAL AND ELECTROMAGNETIC CONTRACTORS 61
ELECTRONIC SUPPLIES (including Cables and Location Instruments) 253
EXPLOSIVES 291
FOREWORD 7
GRAVITY METER CONTRACTORS 49
INDEX TO COMPANY LISTINGS 534
INSTRUMENTS-GEOPHYSICAL (Field) 209
INSTRUMENTS-OCEANOGRAPHIC 244
LOGGING SERVICE (Core Hole) 128
MAGNETOMETER CONTRACTORS 57
MARSH BUGGIES AND TRACKED VEHICLES 330
MINING COMPANIES USING GEOPHYSICAL TECHNIQUES 428
NEAR SURFACE SURVEYS (including Engineering and Mining) 82
NON-DYNAMITE ENERGY SOURCE EQUIPMENT 262
OIL AND GAS COMPANIES USING GEOPHYSICAL TECHNIQUES 349
PERSONNEL LIST 437
RADIOACTIVITY SURVEYS 84
REMOTE (Satellite) SENSING SERVICES 93
SEISMOGRAPH CONTRACTORS 17
SHOT HOLE CASING 314
SHOT HOLE DRILLING CONTRACTORS 121
SOCIETIES (Geophysical) 337
SOFTWARE (Geophysical) 187
SOIL ANALYSIS CONTRACTORS 83
SUPPLIES AND SERVICES (Peripheral Geophysical) 298
SURVEYING CONTRACTORS (Location) 87
GOVERNMENT AGENCIES UTILIZING GEOPHYSICS 344
VELOCITY DATA 136

Appendix D:

Geophysical Data Examples and Information Sheets

Depiction of geophysical equipment in Appendix D is provided solely for reference purposes. No endorsement of manufactures or equipment is intended.

Magnetometer Example

Portable Proton Memory Magnetometer Model G-856

The G-856 magnetometer automatically measures the absolute value of the earth's magnetic field to a resolution of 0.1 gamma. The 6-pound (2.7 kg) portable G-856 uses a solid-state memory to store up to 1,400 separate readings of the field, time, date, and station number in survey mode, and 2,800 readings with date and time in base station (automatic cycling) mode. Optional memory expansion to four times these capacities is available. Data can be retrieved manually, or the G-856 can be connected via an RS-232 port to a variety of small computers for automatic processing of data, including correction for time variations, averaging, filtering, and generating complete profiles and contour maps. The G-856 is well-suited to a variety of applications in geologic mapping, mining, fault location, archaeology, and magnetic search. The instrument comes with a set of field accessories, sensor, batteries, staff, chest harness, carrying/shipping case, and interpretation and operator's manuals. Processing software to list, plot, contour, and model magnetic data is available for the IBM-PC and other computers.

Specifications

Display:	6-digit display of magnetic field to resolution of 0.1 gamma or time to nearest second. Additional (optional) 3-digit display of station or day of year.
Resolution:	To 0.1 gamma in average conditions.
Accuracy:	One gamma, from −4° to 122°F (−20 to 50°C).
Tuning Range:	20 to 90 kilogammas.
Tuning Mechanism:	Push button from keyboard with current value displayed on request.
Gradient Tolerance:	To 1800 gammas/meter. When high gradients increase signal decay, partial reading is maintained at an accuracy consistent with data.
Memory:	Stores 1,400 readings in portable mode. In base-station operation, records last 4 digits of field at discrete intervals, allowing storage of more than 2,800 readings.
Output:	Plays data out in standard RS-232 format at selectable baud rates. Also outputs data in byte parallel, character serial BCD for use with digital recorders.
Power:	Operates from 9 "D" cell flashlight batteries or 12 V external power. May be operated at 18 V external power to improve resolution.
Size:	Instrument console: 7 x 10½ x 3½ in. (177 x 267 x 89 mm); 6 lbs. (2.7 kg) Sensor: 3½ x 5 in. (89 x 127 mm) 4 lbs. (1.8 kg) Staff: 1 in. x 8 ft. (25 x 2438 mm) 2 lbs. (1 kg)
Weight:	Shipping, 42 lbs. (18 kg); Net, 18 lbs. (8 kg).

Optional Accessories

G-856-1. Interface Cable

G-856-2. Rechargeable battery pack and charger

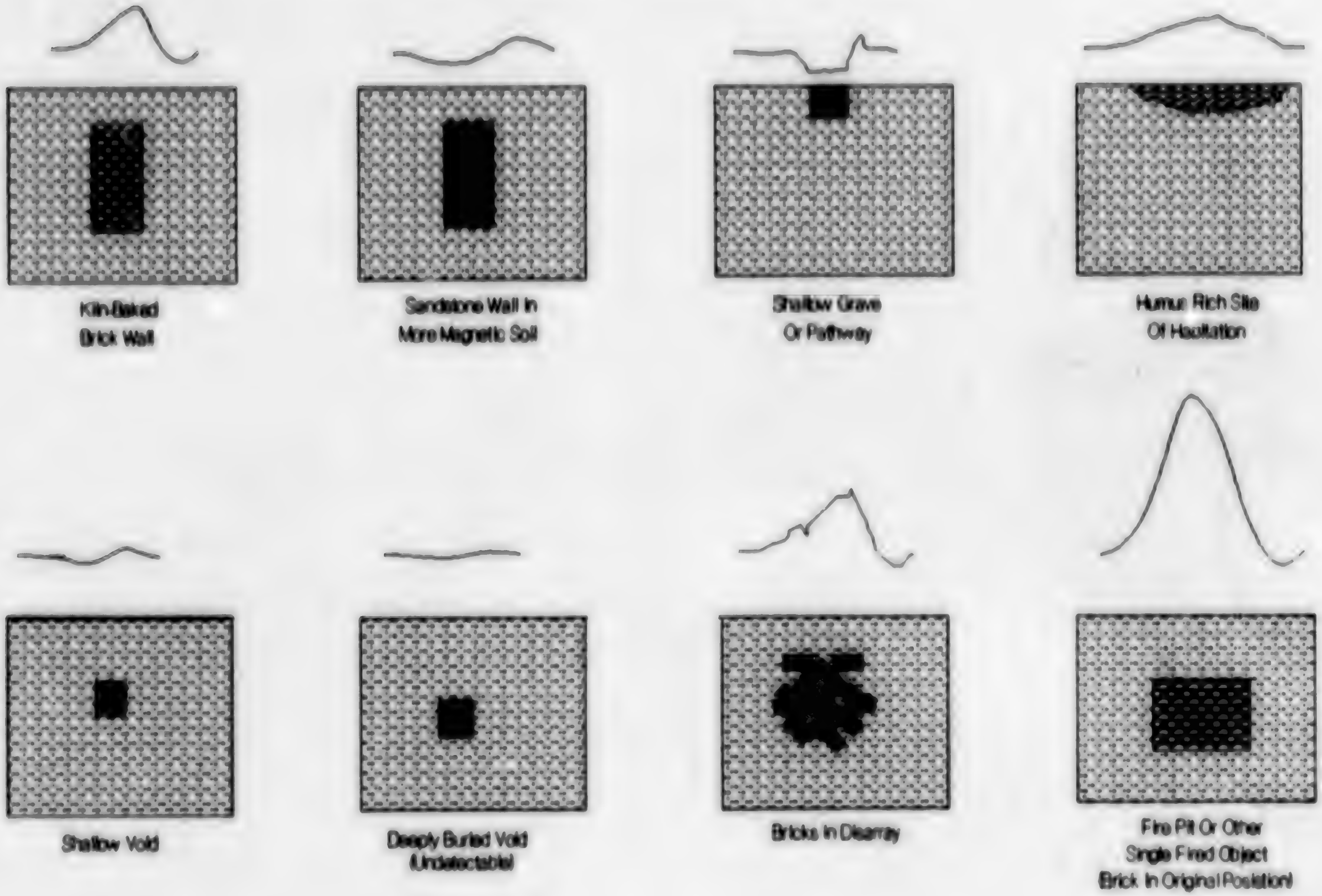
G-856-3. Cold weather battery belt.

G-856-4. Digital tape recorder with interface cables.

Courtsey Geophysical Instrument and Supply Co. (GISCO)

BLANK
PAGE

Archaeological Magnetic Anomalies



Kiln-Baked Brick Wall

Sandstone Wall In More Magnetic Soil

Shallow Grave Or Pathway

Humus Rich Site Of Habitation

Shallow Void

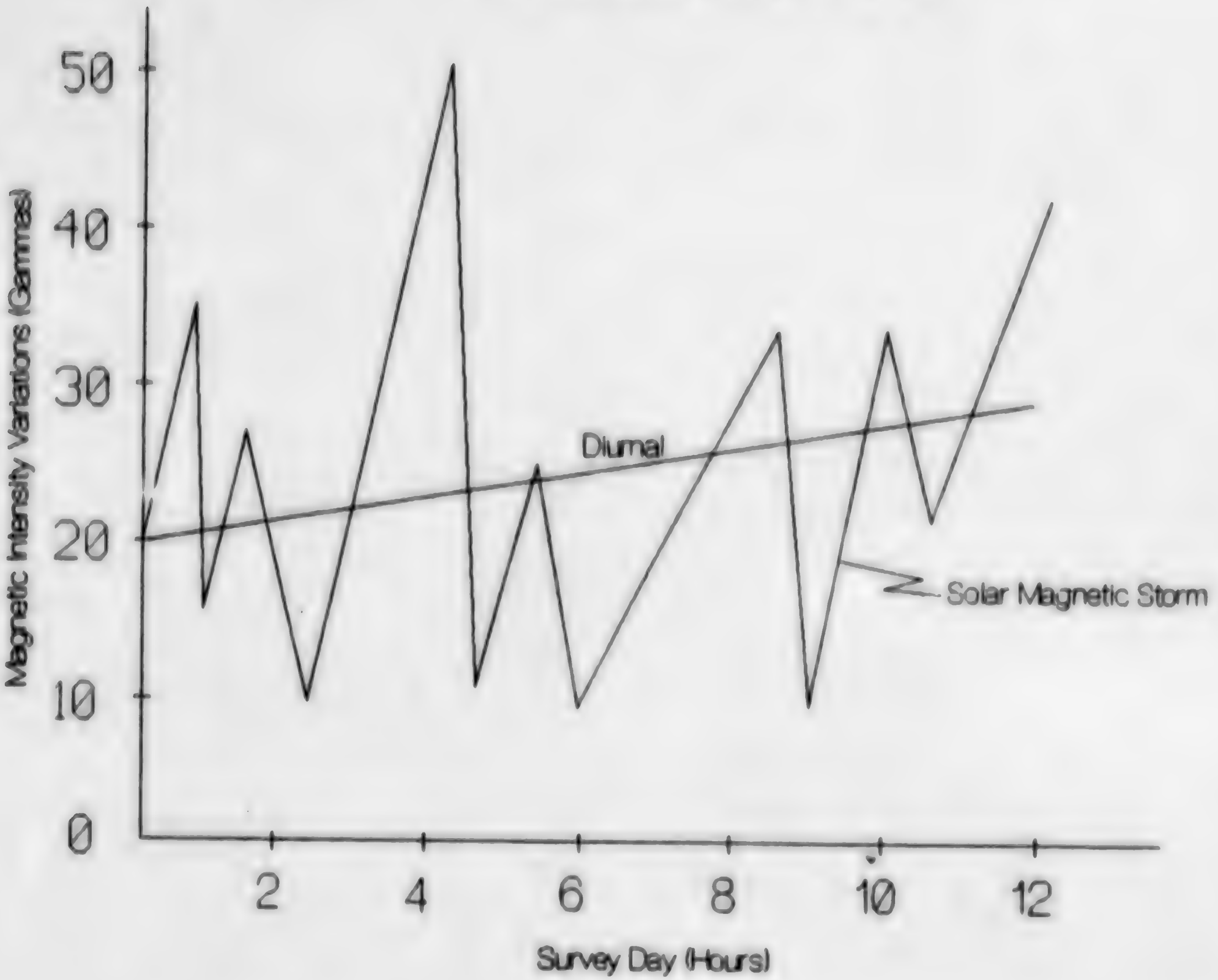
Deeply Buried Void (Undetectable)

Bricks In Disarray

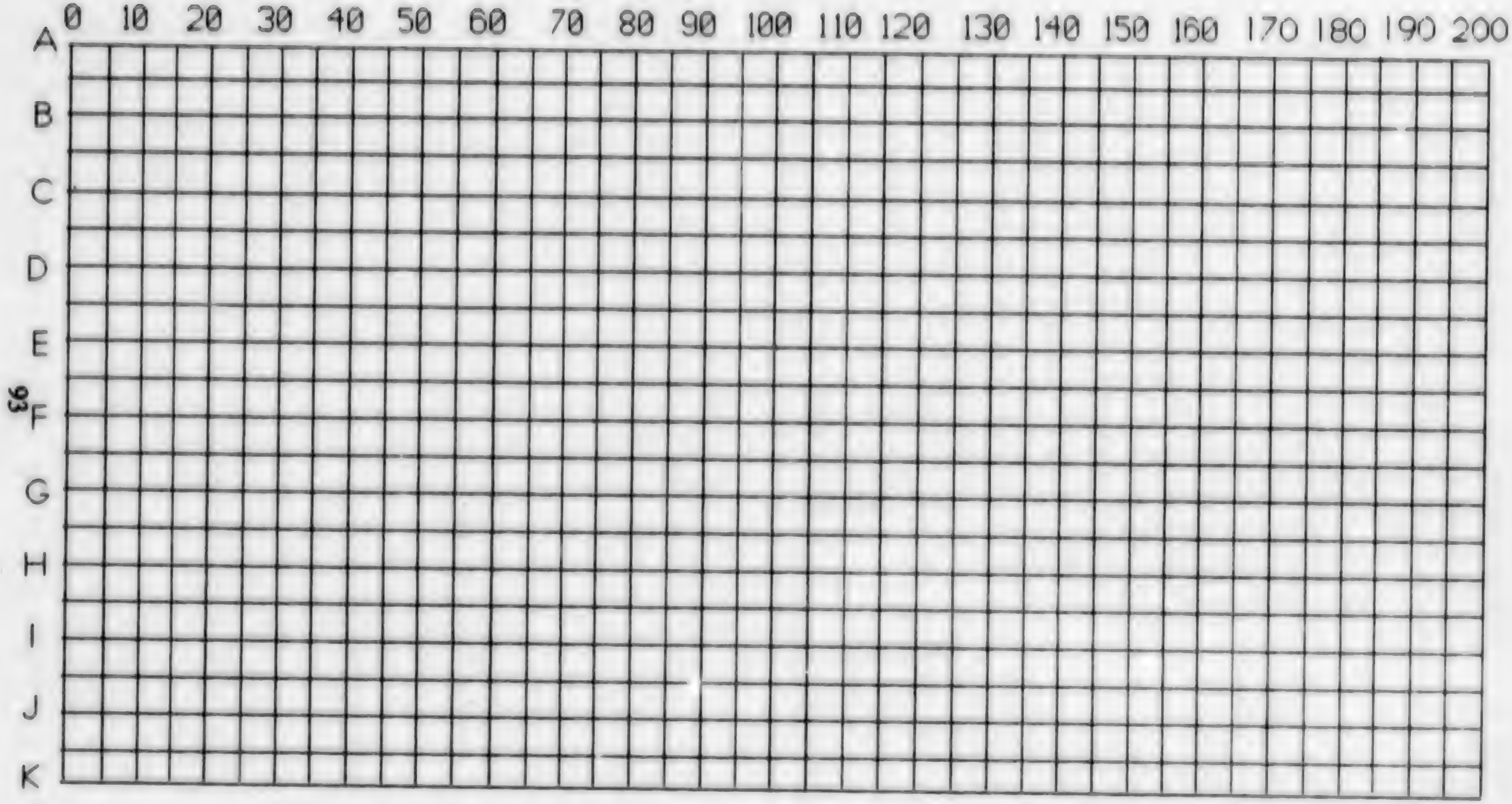
Fire Pit Or Other Single Fired Object (Brick In Original Position)

* Adapted From Applications For Portable Magnetometer Manual, Breiner, 1973

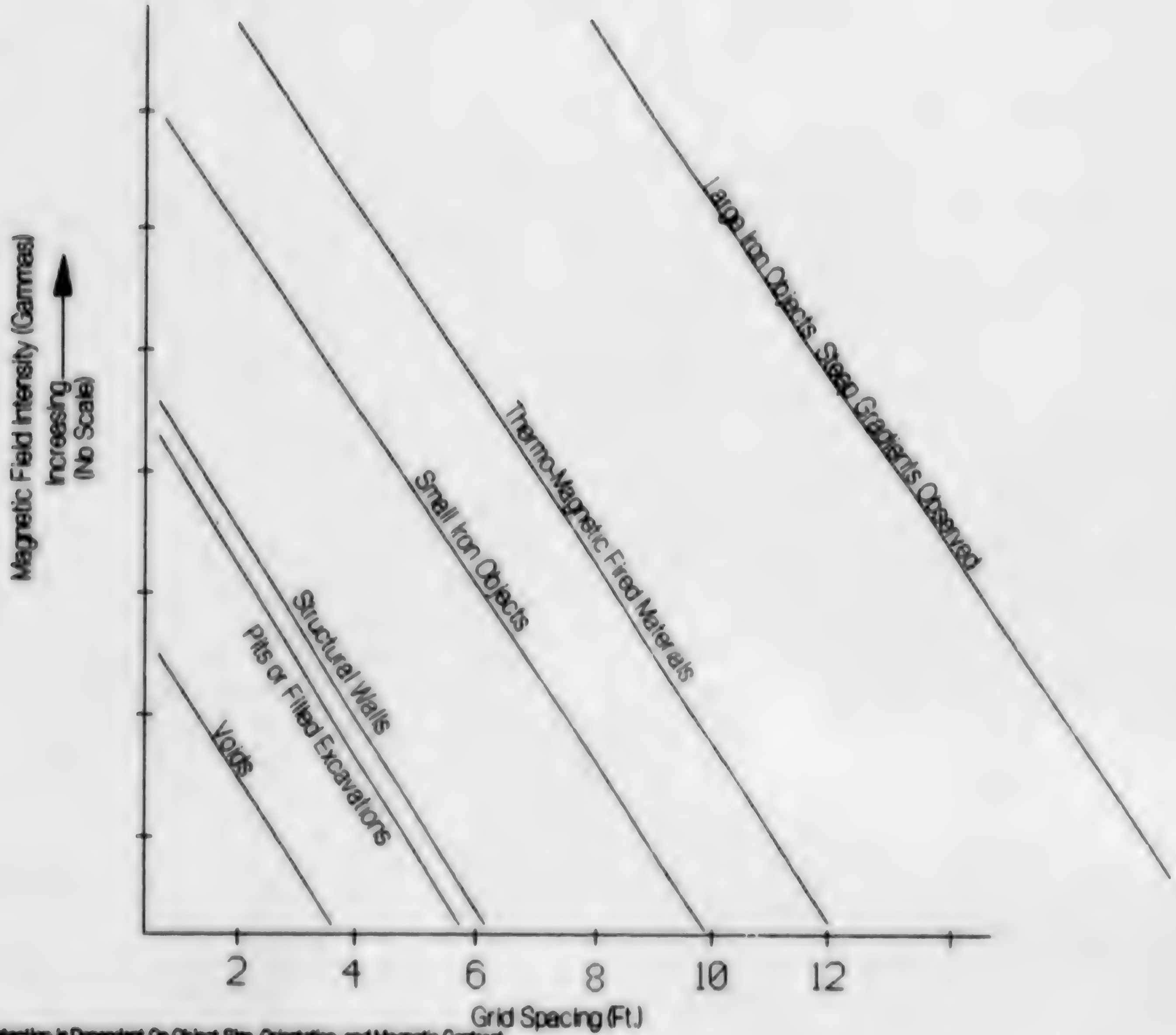
Typical Magnetic Daily Temporal Variations
(North American Continent)



TYPICAL GEOPHYSICAL SURVEY GRID

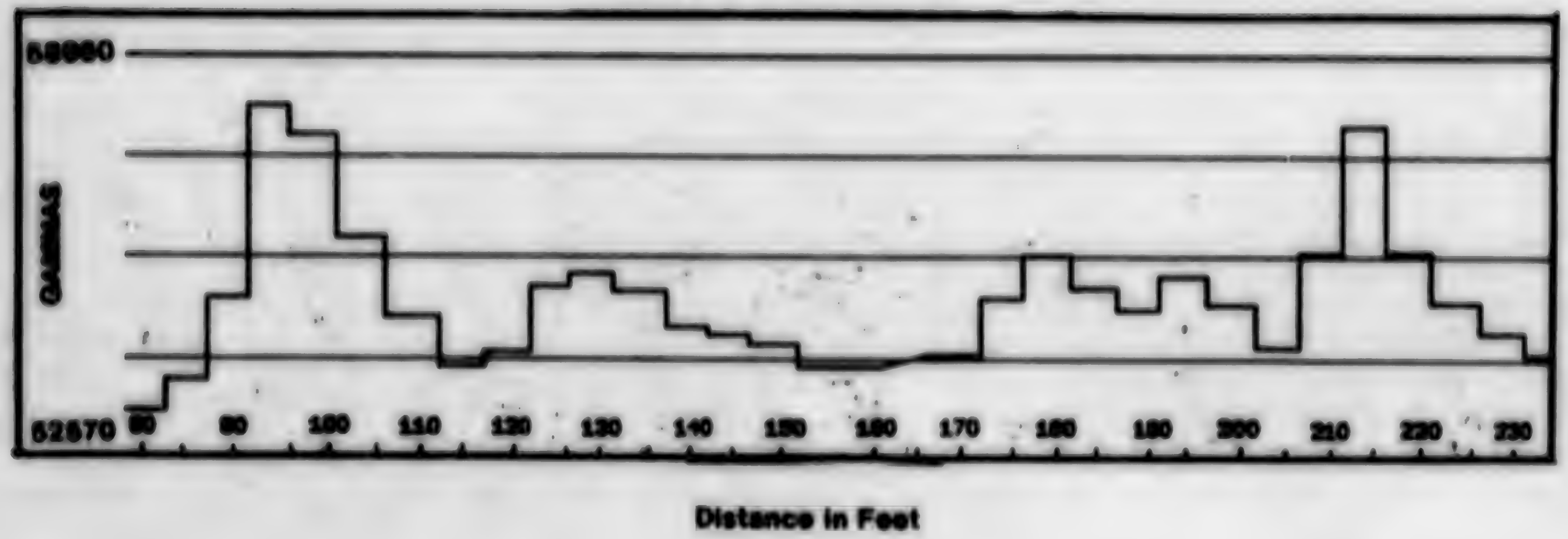


Typical Archaeology Magnetic Anomaly Detection

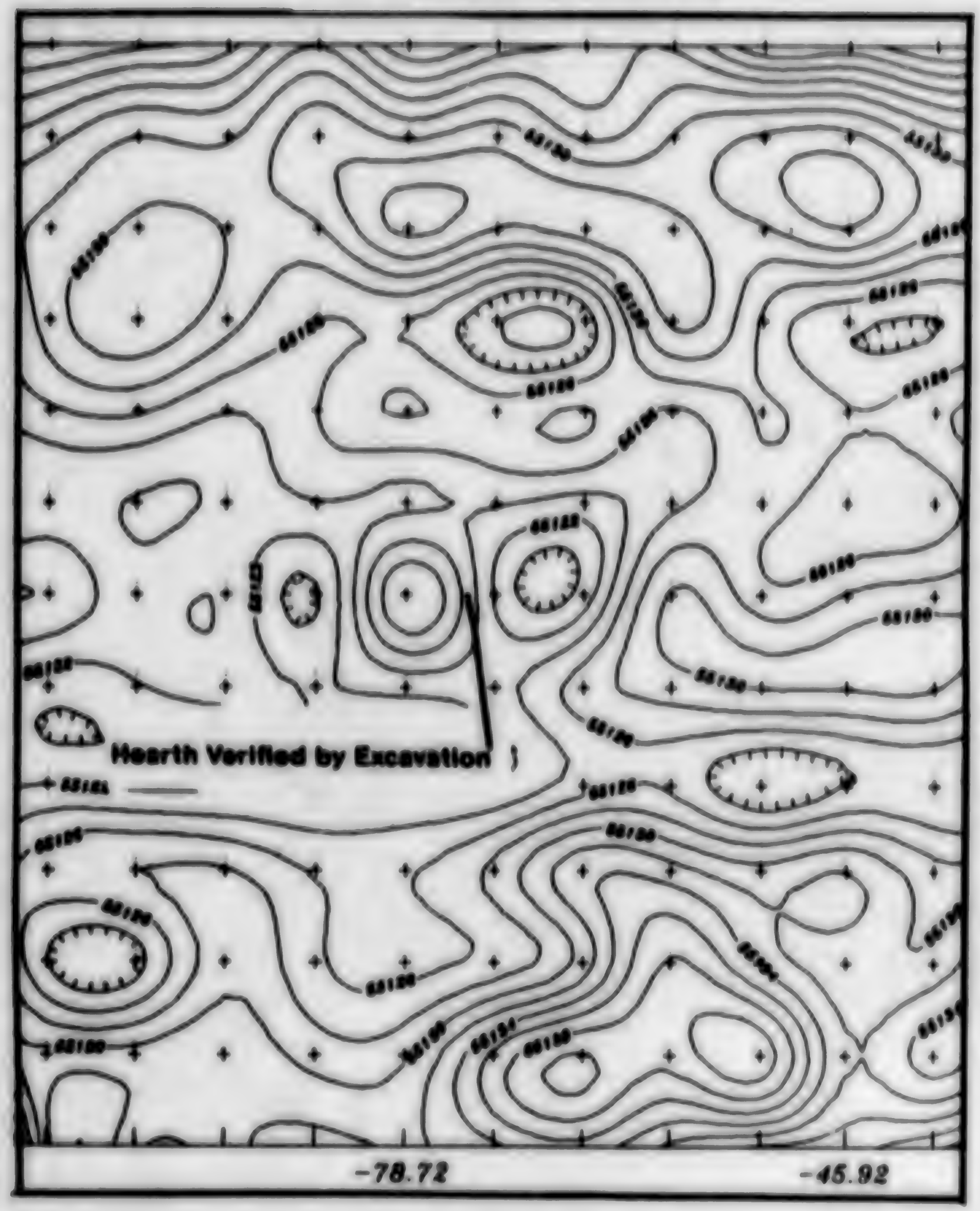


* NOTE- Anomaly Detection is Dependant On Object Size, Orientation, and Magnetic Contrast

Total Magnetic Field Survey Profile

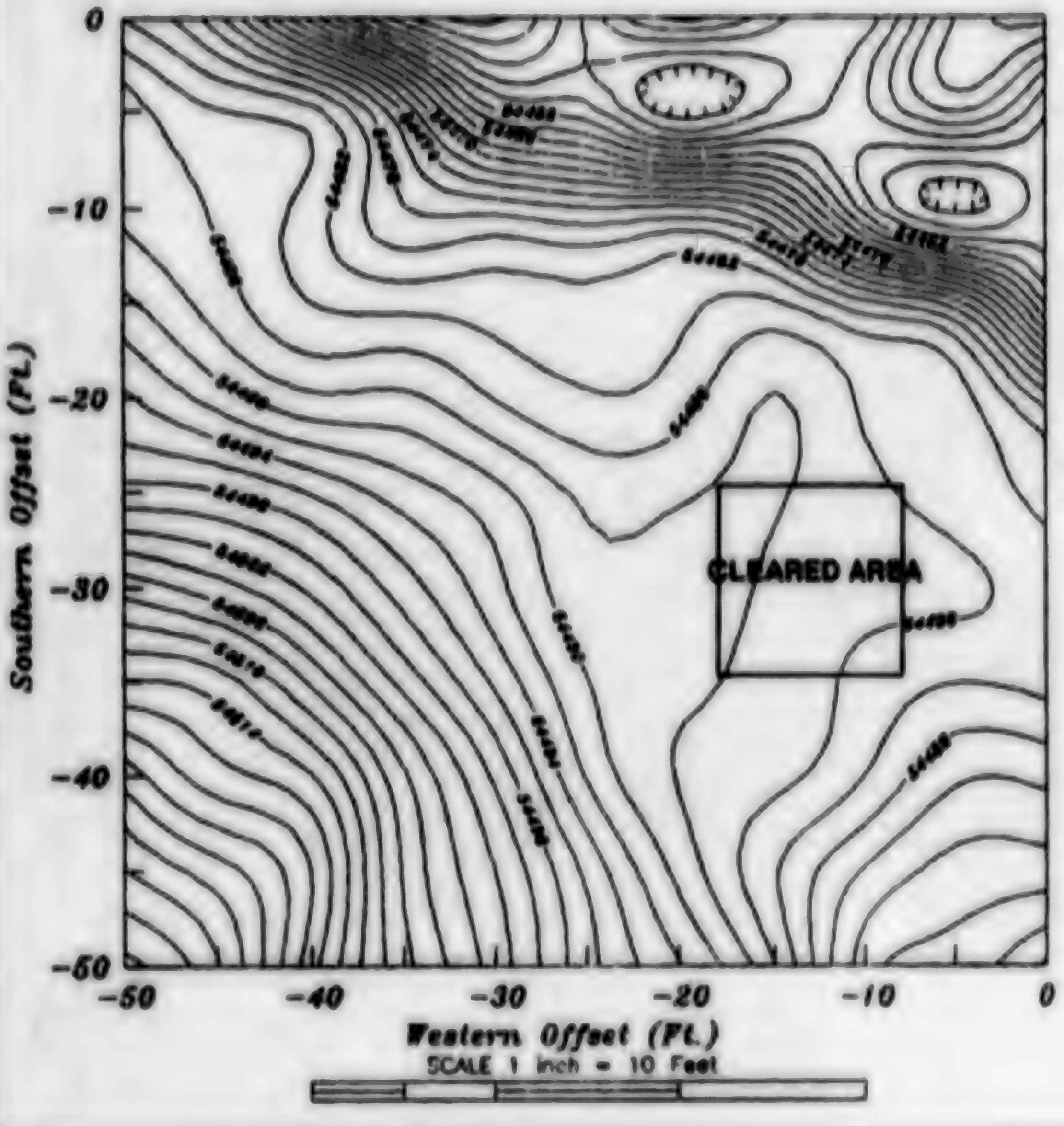


Total Magnetic Field Contour Map



2-Meter Grid

Magnetometer Survey - Location 3C543



MAGNETIC FIELD DATA SHEET

CLIENT________________

PROJECT________________

JOB NUMBER____________

BASE LOCATION________________

INSTRUMENT________________

DATE________________

LOCATION____________

LINE________________

OPERATOR____________

MAP SHEET__________

COMMENTS:

OBS#	STATION	READING	TIME	COMMENTS

Davenport & Hadley 1986

Typical Gravity Meters

Photo Courtesy LaCoste & Romberg Gravity Meters, Inc.

GRAVITY FIELD DATA SHEET

CLIENT______________

PROJECT_____________

JOB NUMBER__________

BASE LOCATION_____________

INSTRUMENT_______________

DATE______________

LOCATION__________

LINE______________

OPERATOR__________

MAP SHEET_________

COMMENTS:

BS#	STATION	READING	TIME	LAT.	LONG.	ELEV.	COMMENTS

Davenport & Hadley
1986

Earth Resistivity Meter Model 2350B

Model 2350B Earth Resistivity Meter and System is designed for extended shallow depth earth exploration, pollution monitoring, and archaeological problems. Exploration projects include the location of ground water aquifers, gravel or rock deposits, ore bodies, topographic highs or lows on a bedrock surface, areas of weathered bedrock on an otherwise solid rock surface, or determining the variations in depth of subsurface conditions, for example, soil layer overlying gravel or bedrock, or sand overlying clay over bedrock. Pollution monitoring includes continuing studies of ground water levels and salinities, delineation of pollutant plumes, monitoring of landfills, leakage monitoring of storage lagoons, and studies of the movement of organic pollutants. Archaeological sites have been successfully mapped in detail before excavation. Users include geophysicists, geologists, environmentalists, civil engineers, hydrologists, sand and gravel operations, sanitary engineers, mining engineers, highway engineers, contractors, quarry operators, drillers, and archaeologists.

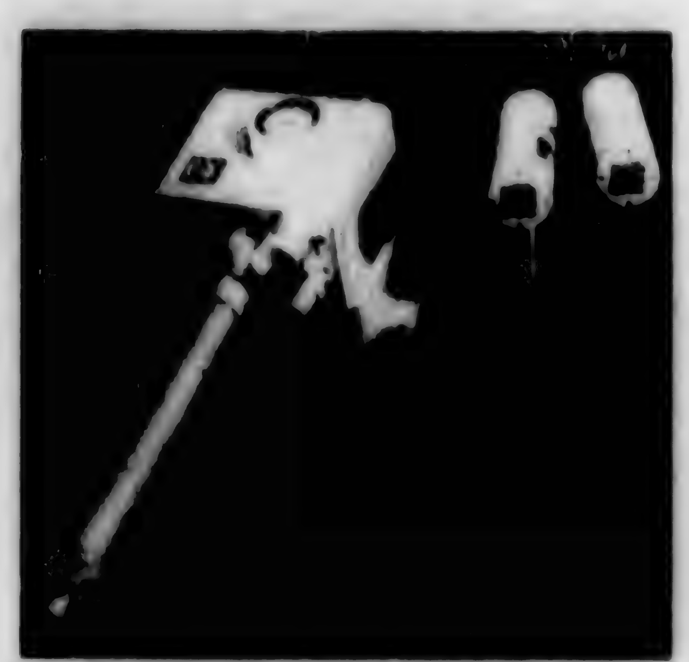
Specifications

High Voltage	720 Volts (peak-to-peak)
Nominal Excitation Frequency	11 Hz to minimize cable coupling and skin effect
Frequency Control Adjustment	±10% to minimize extraneous "beat frequency" earth current interference
Direct Digital Reading of Resistance	Quantity measured · [illegible]
Resolution	One part in 10,000 maximum
Accuracy	±2% per range setting
Electrode Balance Circuit	One 0.001 multiplier range, to maximize accuracy at high electrode resistance
Five Range Scales	0.001, 0.01, 0.01, 1.0, 10.0. To cover all types of sub-surface materials and situations.
All Solid State	Integrated circuit construction for long service life and stability.
Current	Automatically controlled to a nominal 20 milliampere.
Current Monitor	Separate 0-30 milliampere meter for continuous monitoring of electrode current.
Five Terminal System	Model 2350B can be used with all electrode spreads: Wenner, Lee, Schlumberger, Dipole-Dipole, Bristow, Pole-Dipole, Mise-a-la-Masse, [illegible] and others.
Operation	Operates at the touch of a button automatically without a separate power pack.
Test Circuit	Built in to check operation at any time.
Portable and Lightweight	Weight: 14 lbs. (6.4 kg). Packaged in a designed weather resistant case, 6 x 12 x 10 inches (152 x 305 x 254 mm). Complete with self-contained power pack.
Model 2350B Earth Resistivity Meter	Provided complete with batteries, instructions and interpretation procedures.

Accessories

Model 2225 Heavy Duty Reel-Electrode Accessory Kit includes four 24" zinc plated electrodes, four reels with copper-weld vinyl nylon insulated cable for 300 feet (90 meters) "A" spacing plus Lee electrode and cable.

VLF Meter



VLF Resistivity Meter EM-16/16R

The EM16R is a simple, button on attachment to the EM16 converting it to a direct reading terrain resistivity meter. The EM16R interfaces a pair of potential electrodes to the EM16 enabling the measurement of the ratio of, and the phase angle between, the horizontal electric and magnetic fields of the plane wave propagated by distant VLF radio transmitters.

The EM16R is direct reading in ohm-meters of apparent ground resistivity. If the phase angle is 45°, the resistivity reading is the true value and the earth is uniform to the depth of exploration (i.e., a skin depth). Any departure from 45° of phase indicates a layered earth. Two layer interpretation curves are supplied with each instrument to permit an interpretation based on a two layer earth model.

This highly portable resistivity meter makes an ideal tool for quick geological mapping and has been used successfully for a variety of applications.

- Detection of massive and disseminated sulphide deposits.
- Overburden conductivity and thickness measurements.
- Permafrost mapping.
- Detection and delineation of industrial mineral deposits.
- Aquifer mapping.

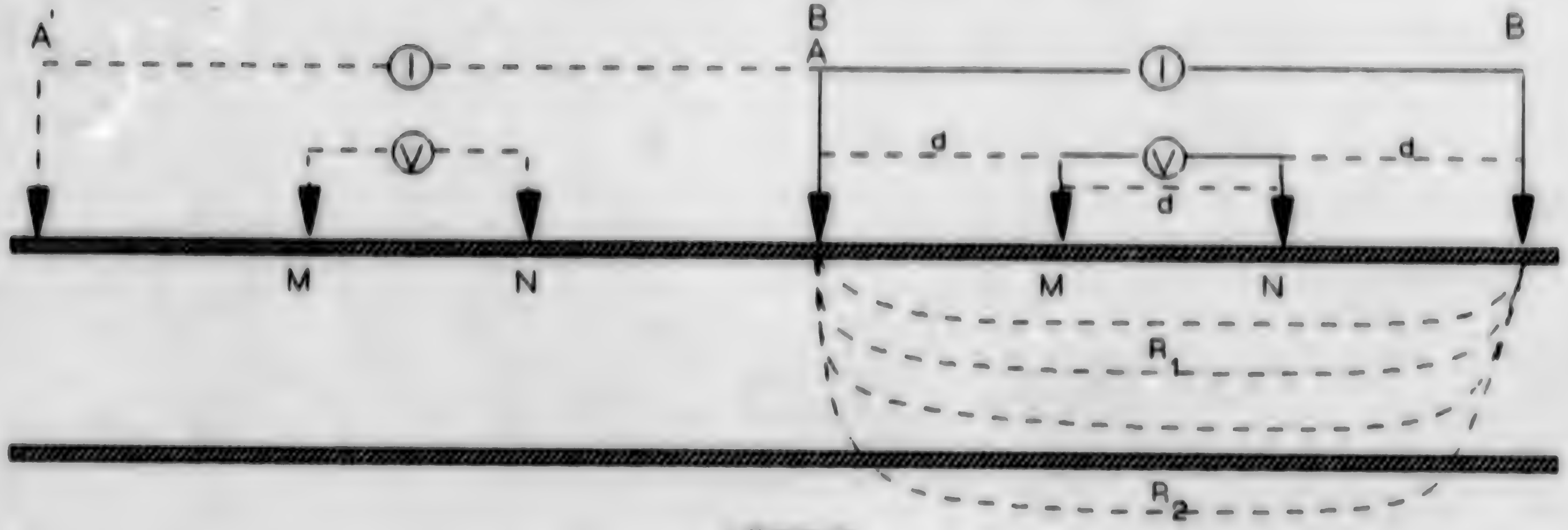
Specifications

Measured Quantity.	Apparent Resistivity of the ground in ohm-meters. Phase angle between E_x and H_y in degrees.
Resistivity Ranges.	10- 300 ohm-meters 100- 3,000 ohm-meters 1000- 30,000 ohm-meters

GISCO

BLANK
PAGE

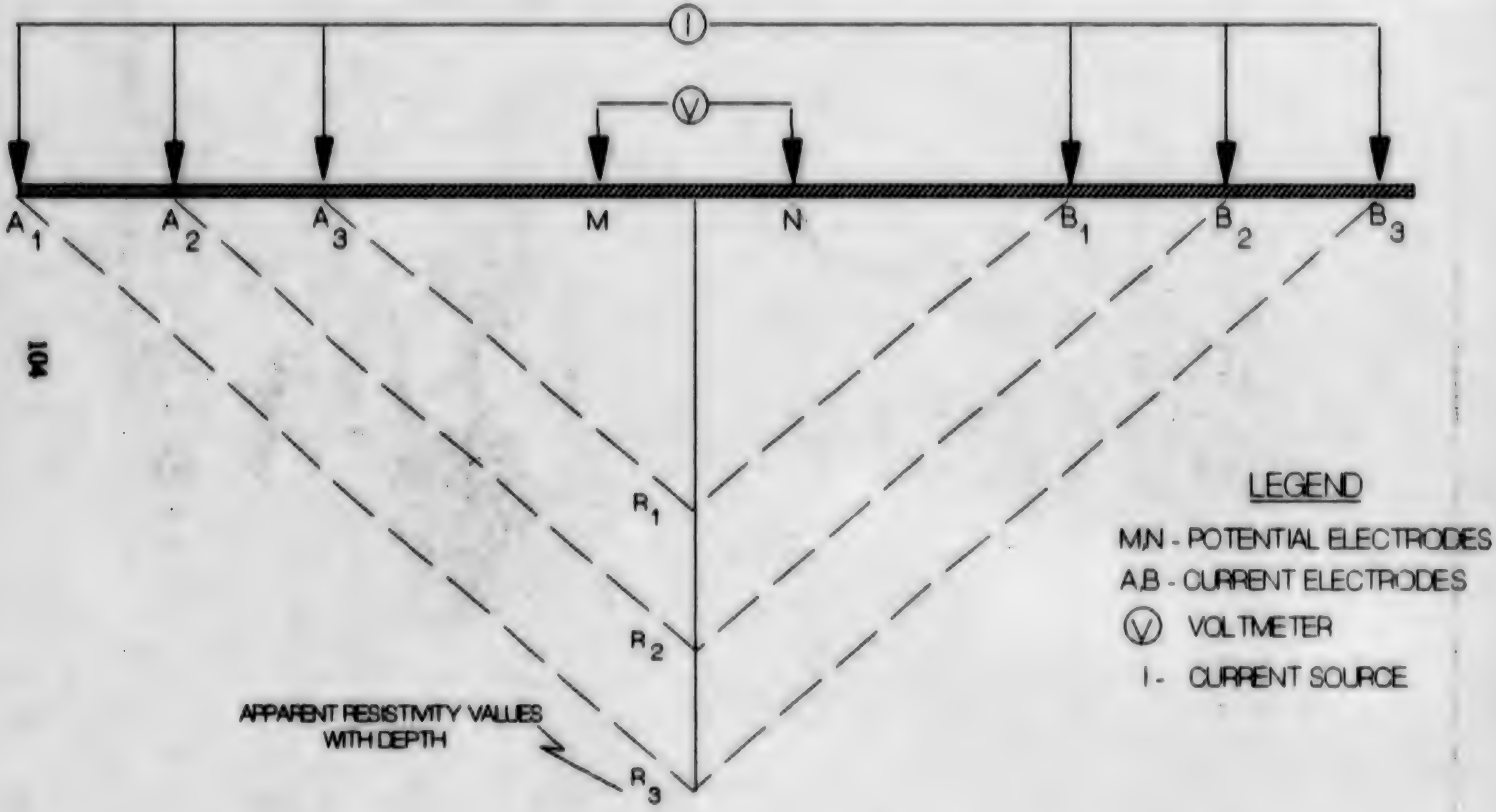
WENNER ELECTRODE ARRAY

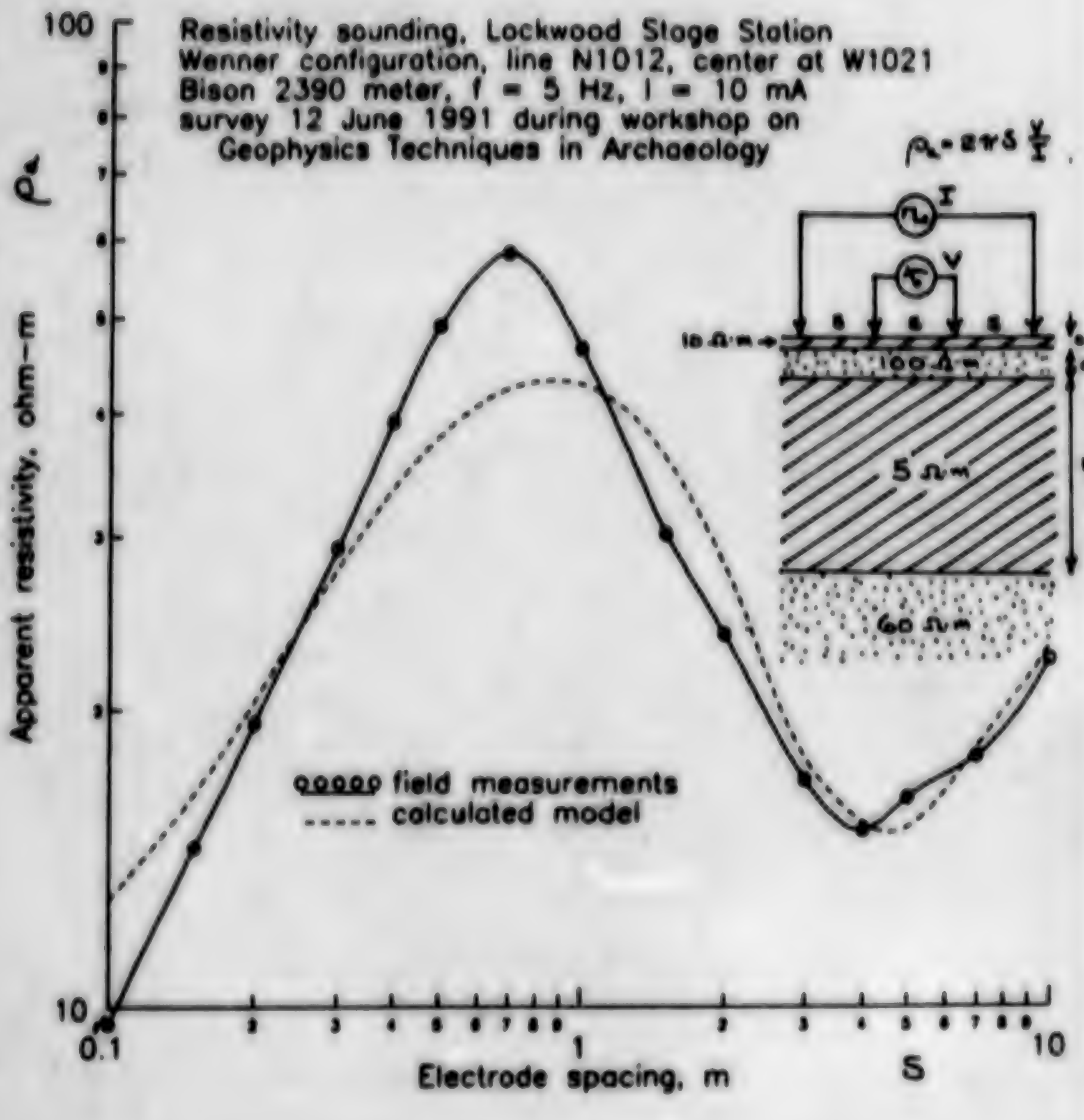


LEGEND

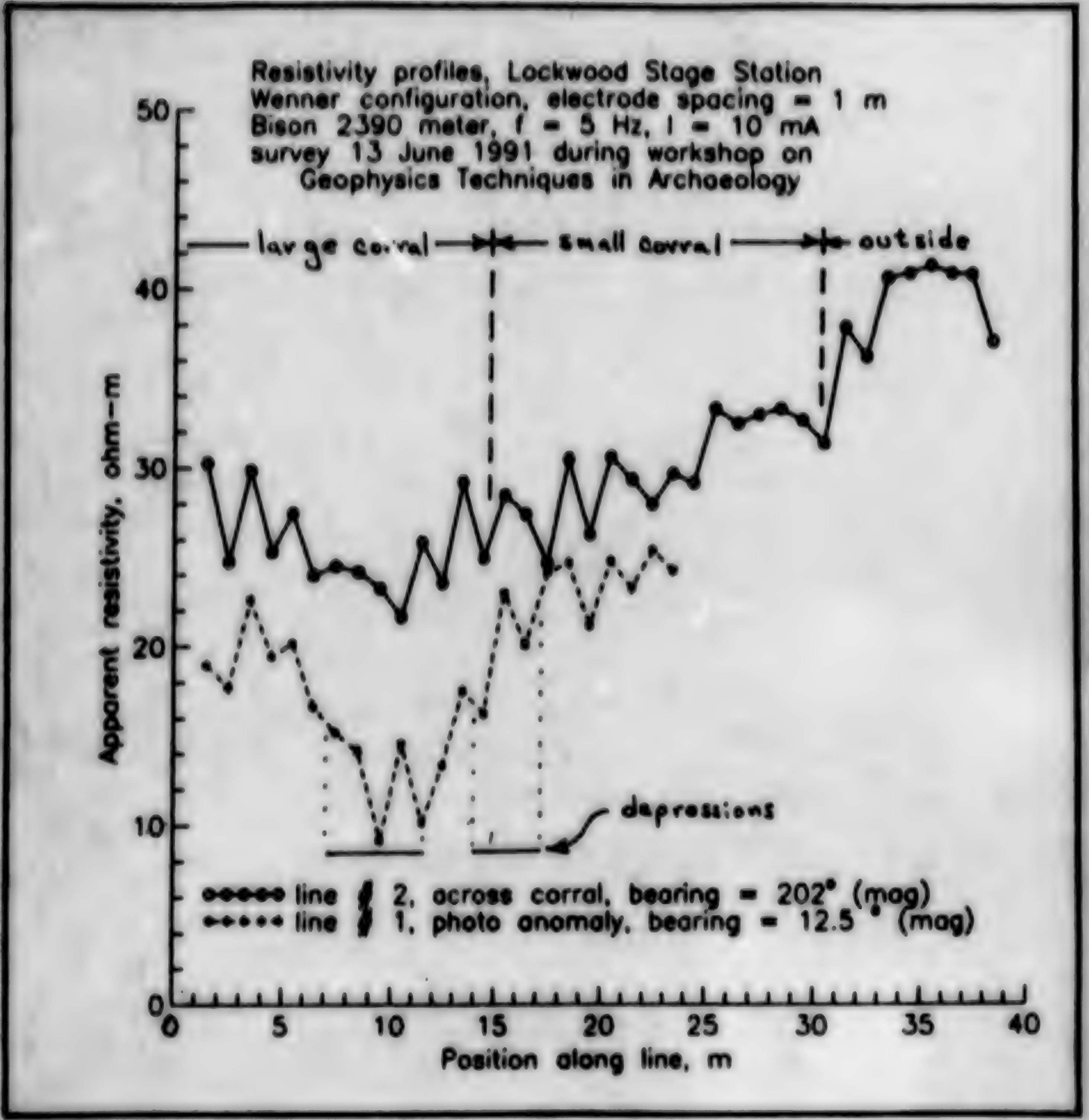
M,N - POTENTIAL ELECTRODES
A,B - CURRENT ELECTRODES
Ⓥ VOLTMETER
I - CURRENT SOURCE
d - ELECTRODE SEPARATION

SCHLUMERGER ARRAY
VERTICAL ELECTRICAL SOUNDING




Resistivity sounding, Lockwood Stage Station
Wenner configuration, line N1012, center at W1021
Bison 2390 meter, f = 5 Hz, I = 10 mA
survey 12 June 1991 during workshop on
Geophysics Techniques in Archaeology
$\rho_a = 2\pi S \frac{V}{I}$
I
V
S
S
S
10 Ω·m
100 Ω·m
5 Ω·m
60 Ω·m
1.9
ooooo field measurements
----- calculated model
Apparent resistivity, ohm-m
ρ_a
100
9
8
7
6
5
4
3
2
10
0.1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
Electrode spacing, m
S

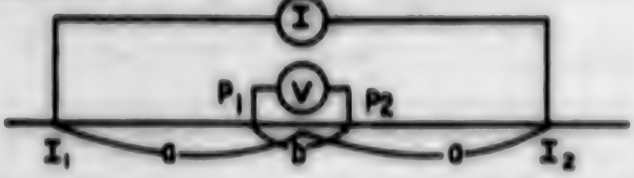
B. Bevan


Resistivity profiles, Lockwood Stage Station
Wenner configuration, electrode spacing = 1 m
Bison 2390 meter, f = 5 Hz, I = 10 mA
survey 13 June 1991 during workshop on
Geophysics Techniques in Archaeology
large corral
small corral
outside
depressions
line # 2, across corral, bearing = 202° (mag)
line # 1, photo anomaly, bearing = 12.5 ° (mag)
Apparent resistivity, ohm-m
0
10
20
30
40
50
Position along line, m
0
5
10
15
20
25
30
35
40

B. Bevan

ELECTRICAL RESISTIVITY DATA SHEET

FEATURE ______ PROJECT ______ STATE ______
LINE NO. ______ LOCATION ______ SURVEY DIRECTION ______
EQUIP ______ ARRAY SCHLUMBERGER OPERATOR ______ DATE ______
GEOMETRIC FACTOR: $\pi a^2/b$



I_1, I_2 – Current electrodes P_1, P_2 – Potential electrodes

STATION	ELECTRODE SPACING -METERS-		TRANSMITTER CURRENT (I) -MILLIAMPS-	RECEIVER	VOLTAGE (E) -MILLIVOLTS-	FREQUENCY	COMPUTATIONS			COMMENTS
	a	b					$\pi a^2/b$ (K)	E/I (R)	APPARENT RESISTIVITY (KR) -Ω.m-	

Davenport & Hadley 1986

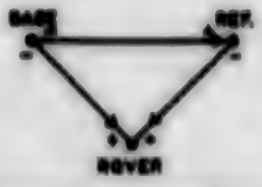
SELF POTENTIAL DATA

Sheet____of____

Project________________
Location________________
Line No.________________
Date ____/____/____
Operator(s)________________
____

Instrument model________________ Serial No.________________
Electrode type________________ Electrolyte________________
SP Station________________ =Dam Station________________
BASE ELECTRODE NEGATIVE BY DEFINITION

See reverse side for map



(Base→Ref.) +
(Ref.→Rover) =
(Base→Rover)

STATION	POTENTIAL	TIME	CONTACT	DRIFT CORRECTION			NOTES
	sign, reading		res.(Ω)	① base→ref	② ref.→rover	③ base→rover	

DRIFT CORRECTIONS: ①+③ Perform once at begining & once at end of line. (Electrodes in bath & away from direct sun) ② Perform every 30 minutes.

Davenport &
Hadley 1986

Ground Conductivity Meter
EM-38

Designed to be particularly useful for agricultural applications such as field surveys of soil salinity, the EM-38 can cover large areas quickly without ground electrodes. The EM-38, based on the same patented principles as all Geonics Ground Conductivity Meters, provides depths of exploration of 0.75 meters in the horizontal dipole mode — normal operating position, — 1.5 meters in the vertical dipole mode — lying on its side (see Geonics Technical Notes TN5 and TN6).

Very lightweight and only one meter long, the EM-38 provides rapid surveys with excellent lateral resolution. Measurement is normally made by placing the instrument on the ground and noting the meter reading. However with this instrument it is also possible to record the meter reading at various instrument heights above the ground (from zero to two meters) and thus, using the supplied interpretation curves, to fully resolve a two-layered earth.

To further enhance the mapping potential of the EM-38, measurement can also be made of the magnetic susceptibility of the soil.

In addition to its agricultural application, the EM-38 has proven to be very useful in other areas where a knowledge of the near surface conductivity can be applied, such as general geotechnical mapping and archaeology.

Specifications

Measured Quantity	Apparent conductivity of the ground in millimhos per meter.
Primary Field Source	Self-contained dipole transmitter
Sensor	Self-contained dipole receiver.
Intercoil Spacing	1 meter
Operating Frequency	13.2 kHz
Power Supply	9V Transistor Radio Battery (eg. Mallory MN1604).
Conductivity Ranges	0-10, 100, 300, 1000 millimhos per meter.
Measurement Precision	±5% of full scale deflection
Battery Life	20 hours continuous for MN1604.

GISCO

Ground Conductivity

Ground Contactivity Electromagnetic Meter EM-31D

The EM31 provides a measurement of terrain conductivity without ground electrodes or contact using a patented electromagnetic inductive technique.

This instrument is direct reading in millimhos per meter and, over a uniform half space reads identically with conventional resistivity instruments with fixed array spacings. Using the inductive method, surveys are readily carried out in regions of high resistivity such as sand, gravel, permafrost and bedrock.

The effective depth of exploration is about six meters making it ideal for many geotechnical and groundwater contaminant surveys. Other important advantages of the EM-31 over conventional methods are the speed with which surveys can be conducted, the precision with which small changes in conductivity can be measured and the continuous readout while traversing the survey area. The new EM-31D provides an analog output of both the quadrature-phase and in-phase components which can be recorded continuously on a dual channel recorder. The in-phase component is especially useful for detecting small, shallow ore bodies and, in waste site surveys buried metal drums.

Specifications

Measured Quantity	Apparent conductivity of the ground in millimhos per meter
Primary Field Source	Self-contained dipole transmitter
Sensor	Self-contained dipole receiver
Intercoil Spacing	3.66 meters
Operating Frequency	9.8 kHz
Power Supply	8 disposable alkaline "C" cells (approx. 20 hrs. life continuous use)
Conductivity Ranges	3, 10, 30, 100, 300, 1000 millimhos/meter
Measurement Precision	±2% of full scale
Measurement Accuracy	±5% at 20 millimhos per meter
Noise Level	<0.1 millimhos per meter
Operator Controls	Mode switch Conductivity Range switch Phasing Potentiometer Coarse Inphase Compensation Fine Inphase Compensation

Ground Conductivity Electromagnetic System EM-34-3

Operating on the same principles as the EM-31, the EM-34-3 is designed to achieve a substantially increased depth of exploration and a readily available vertical conductivity profile.

The underlying principle of operation of this patented non-contacting method of measuring terrain conductivity is that the depth of penetration is independent of terrain conductivity and is determined solely by the instrument geometry i.e. the intercoil spacing and coil orientation. The EM-34-3 can be used at three fixed spacings of 10, 20, or 40 meters and in the vertical coplanar (as shown) or horizontal coplanar mode. In the vertical coplanar mode, the instrument senses to approx. 0.75 of the intercoil spacing. In the horizontal coplanar mode, the instrument can sense to 1.5 times the intercoil spacing. For the horizontal coplanar mode, however, coil misalignment errors are more serious than in the vertical mode so greater care must be exercised to achieve the maximum 60 meter depth.

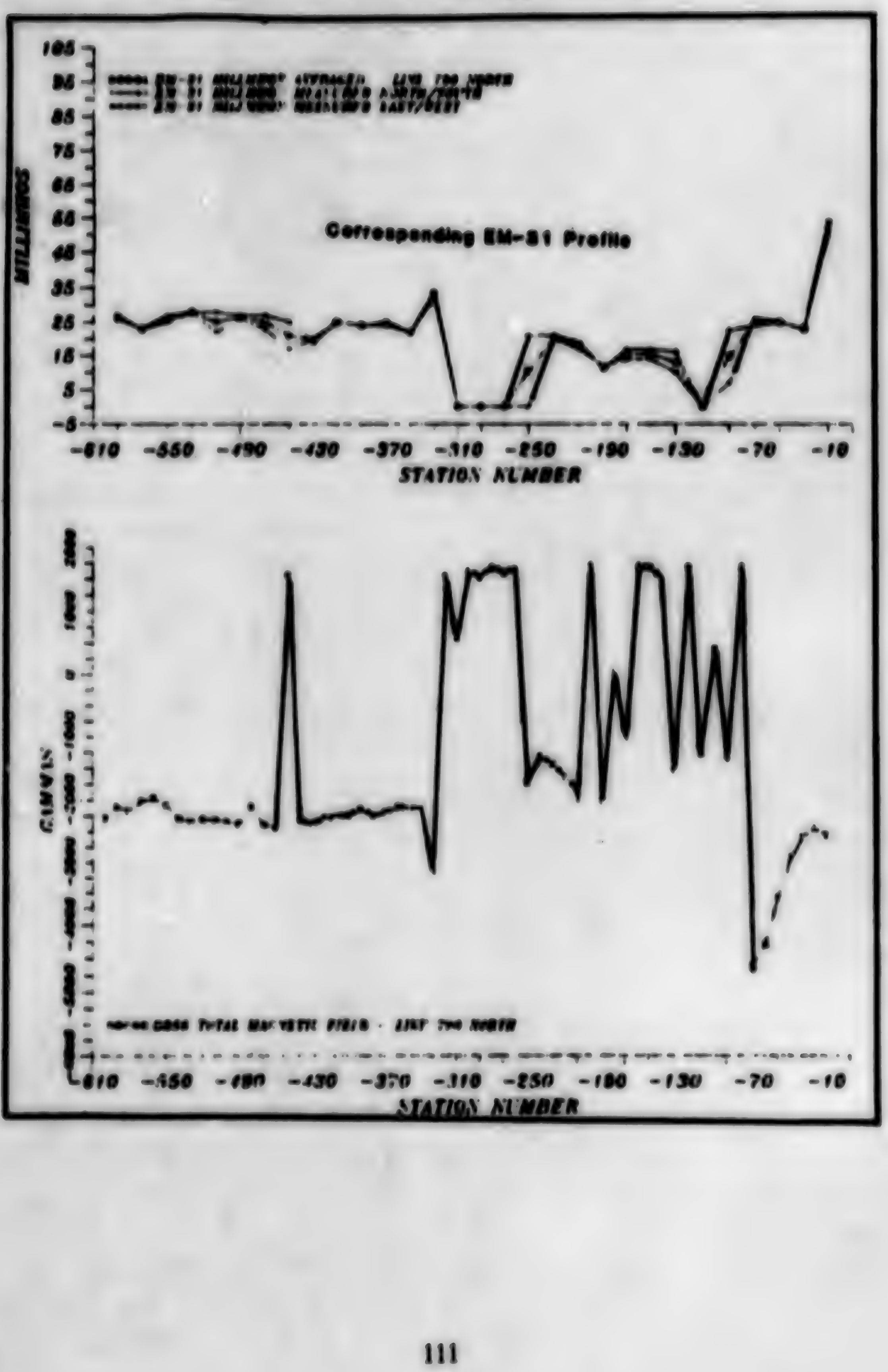
Simple operation, survey speed and straight forward data interpretation makes the EM-34-3 a versatile and cost effective tool for the engineering geophysicist.

Specifications

Measured Quantity	Apparent conductivity of the ground in millimhos per meter.
Primary Field Source	Self-contained dipole transmitter
Sensor	Self-contained dipole receiver
Reference Cable	Lightweight, 2 wire shielded cable
Intercoil Spacing & Operating Frequency	10 meters at 6.4 kHz 20 meters at 1.6 kHz 40 meters at 0.4 kHz
Power Supply	Transmitter: 8 disposable "D" cells Receiver: 8 disposable "C" cells
Conductivity Ranges	3, 10, 30, 100, 300 mmhos/meter
Measurement Precision	±2% of full scale deflection
Measurement Accuracy	±5% at 20 millimhos per meter
Noise Level	<0.2 millimhos per meter

GISCO

Comparison of EM-31 and Magnetometer



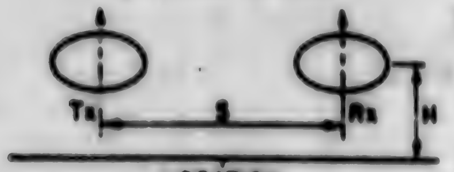
ELECTROMAGNETIC CONDUCTIVITY SOUNDING-DATA SHEET

FEATURE ____________________ PROJECT ____________________ STATE __________

LINE NO. ____________ LOCATION ____________________ SURVEY DIRECTION __________

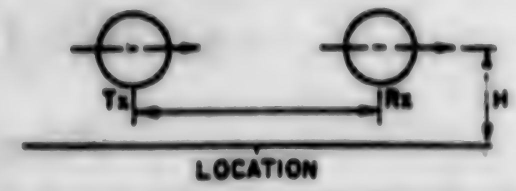
EQUIP. ____________________ OPERATOR ____________ DATE __________

VERTICAL DIPOLE



LOCATION

HORIZONTAL DIPOLE



LOCATION

SEPARATION S (METERS)	DIPOLE MODE (VERT. OR HORZ.)	HEIGHT H (METERS)	SENSITIVITY RANGE (MILLIMHOS/ METER)	CONDUCTIVITY READING	APPARENT CONDUCTIVITY σ@H=0 (MILLIMHOS/ METER)

COMMENTS:

Davenport & Hadley 1986

Subsurface Interface Radar System SIR®-8

SIR®SYSTEM-8 is the most popular Subsurface Interface Radar Equipment in use around the world today. SIR-8 is being used to solve problems on land, ice, fresh water, in tunnels, mines, hazardous waste sites, nuclear power plants, bridges, highways, runways, railroads, dams, and boreholes. The SIR-8 automatically acquires graphic profile records from subsurface features for a variety of geotechnical, engineering, surveillance, environmental, or archeological applications.

SIR®SYSTEM-8 is field proven, easy to use, portable, rugged and it provides data nondestructively not available from any other method. Continuous high resolution profiles are automatically printed in real time or after the survey at a more comfortable location from tape recorded data.

SIR®SYSTEM-8 Control Unit, Model 4800, contains a microprocessor preprogrammed with 8 different signal enhancement programs with 59 variations. The Stacking programs allow weak signals to be "pulled" out of noise and the Background Removal programs eliminate reverberation type noise. The use of the SIR-8 processor in areas with high conductivity materials or for deep penetration significantly aids acquisition of desired data.

SIR®SYSTEM-8 output is continuous profile record showing reflections received as the systems transducer is pulled along the line being surveyed. Data can also be stored on the SIR-8 digital cartridge tape recorder allowing it to be played back through the systems computer many times.

SIR®SYSTEM-8 operates on 12 volt battery Power. An optional Power Supply is available if an AC source is desired. SIR SYSTEM-8 is compatible with a great variety of transducers available to fit your purpose.

SIR® SYSTEM-8 Components

A complete SIR SYSTEM-8 consists of:

(1) Model 4800 Radar Control Unit
(1) Model SR-8004H Graphic Recorder
(1) Model DT-6000 Digital Tape Recorder
(1) Model 38 Program Control Unit
(1) Model 38P Remote Control/Marker
(1) Model 97/3 Power Distribution Unit
(1) Model 3102AP Transducer (500 MHz)
(1) Model 10MS Marker Switch
(1) Model PT31 Calibrator (16 ns)
(1) Transducer Control Cable (30M)
(1) C/U Graphic Cable
(1) C/U Tape Cable
(1) C/U Power Cable
(1) Tape/Graphic Cable
(1) Tape/Power Cable
(1) Graphic/Power Cable
(1) Manual set & a Factory training Course

SIR SYSTEM-8 can be used on land, ice, fresh water or in tunnels, nuclear power plants and boreholes to acquire graphic "pictures" of subsurface features such as soil strata, bedrock, boulders, voids, tunnels, shafts, ice profiles, pipes, cables, gas and water leaks, river and lake bottoms, reinforcing bars, fault mapping, borehole profiling, permafrost profiling, sinkhole prediction, mapping, treasure prospecting, etc., etc., etc.

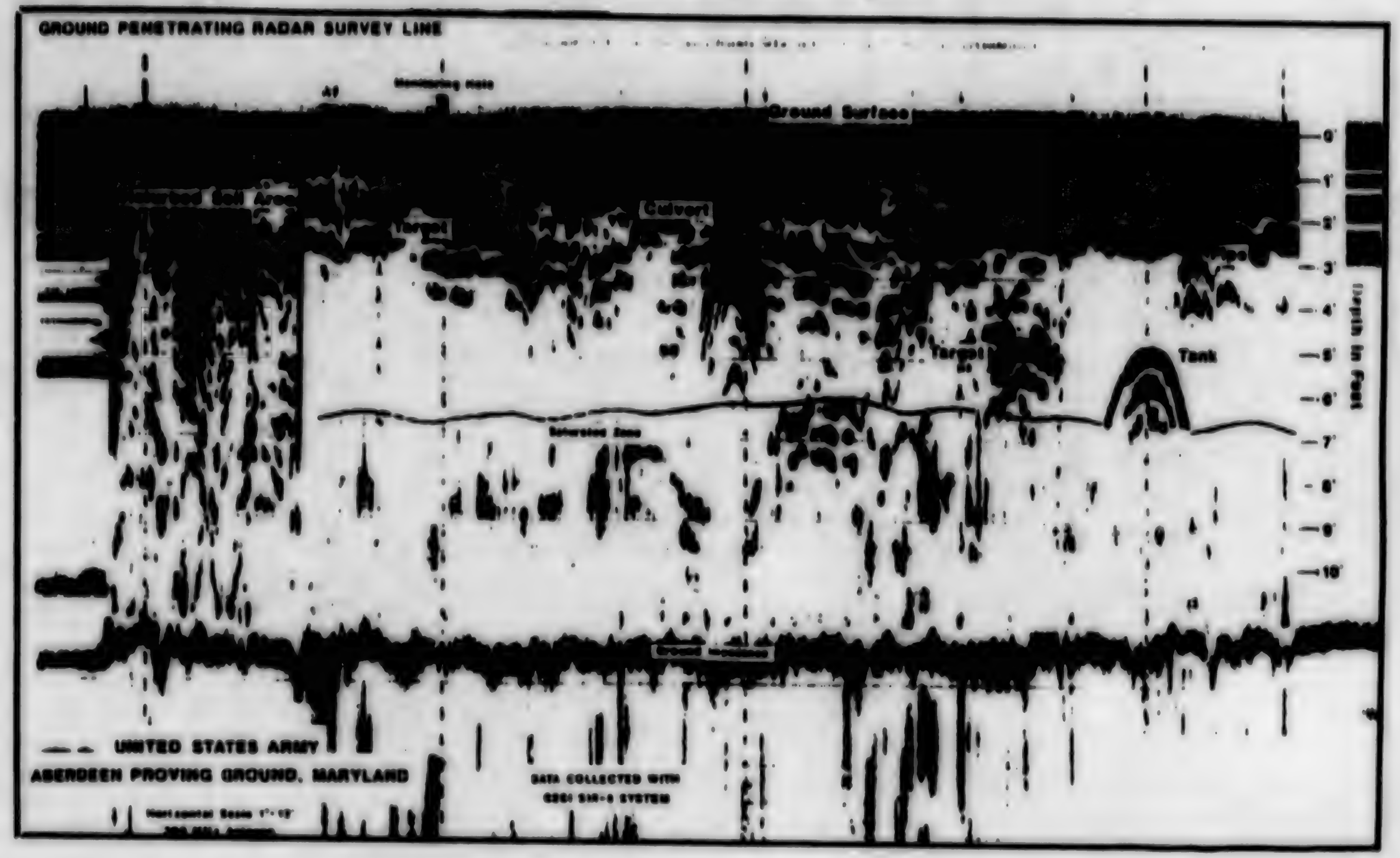
Specifications

SIR® SYSTEM-8 major components are shown on the block diagram. The Model 4800 Control Unit is the heart of the SIR SYSTEM-8 and has controls, an oscilloscope monitor, status indicators and connectors to provide the user with convenient operation of all functions.

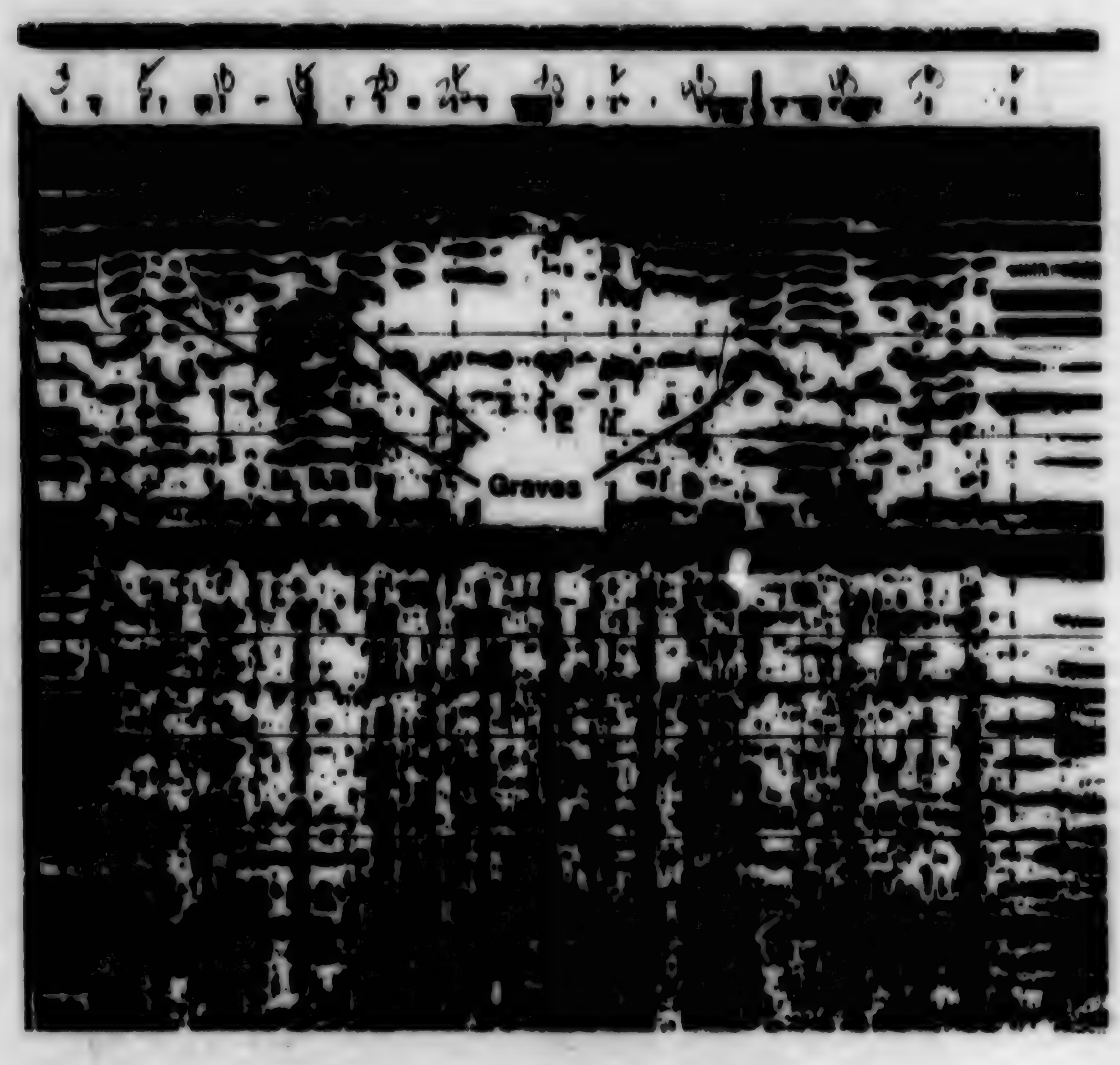
SIR System operation starts when one of its 50KHz trigger pulses fires the transmitting electronics connected to an antenna. The antenna radiates a short duration pulse (1-3 nanoseconds) of electromagnetic energy into the dielectric material it is coupled to. The pulse travels through the material at a speed proportional to the electrical characteristics of the material. If the material changes, the pulse speed will change and some of its energy will be reflected back to the SIR systems receiving antenna. Travel times of the reflections are proportional to depth. The receiving electronics converts the high frequency reflections to a low frequency replica of the reflections which is fed back to the control unit where it is conditioned and then fed to the SIR-8 recorders.

A profile record of reflections is printed on electrosensitive paper by stylus scanning intensity modulated lines across the paper. Scan lines are analogous to depth into the ground, line intensity to reflection amplitude, and paper feed direction to horizontal distance along the survey line. Before the reflection signals are fed to the graphic and/or tape recorders they can be processed to enhance the readability of the profiles: 1) High and Low Pass Filters can be used to condition the signal, 2) A time gain amplifier (range gain) is used to compensate for attenuation of signals from deeper interfaces, 3) A marker generator can be used to add scale lines, a start of scan mark and position markers and, 4) The processor can be used. High and low pass filtering, running and ensemble averaging, background removal, and stacking programs are included.

Typical Ground Penetrating Radar Targets

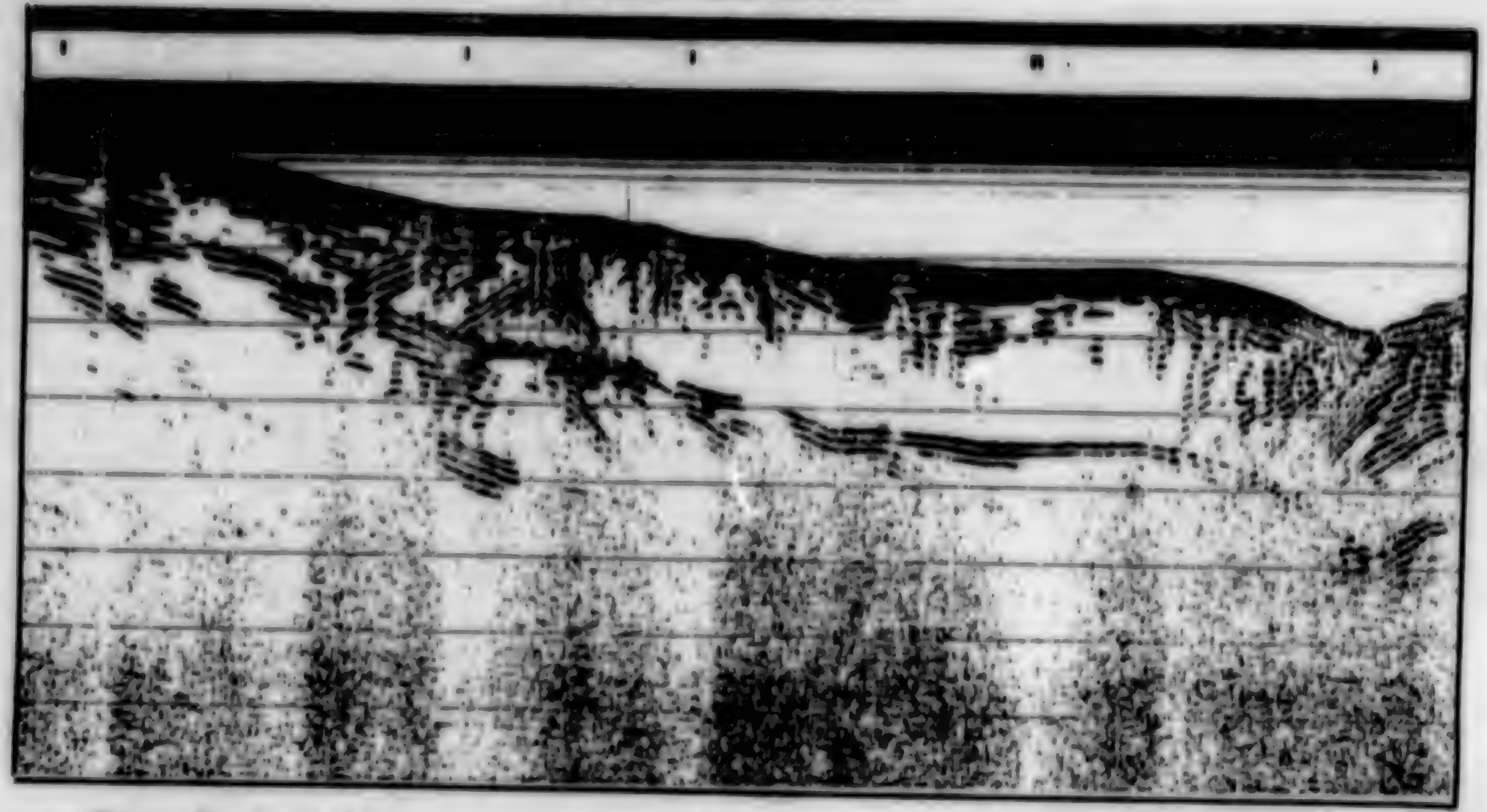


GPR Profile Pioneer Graves (1850) Northeast New Mexico



Horizontal Scale – 5 Ft. 300 MHz. Antenna

GPR Profile Floated Across River



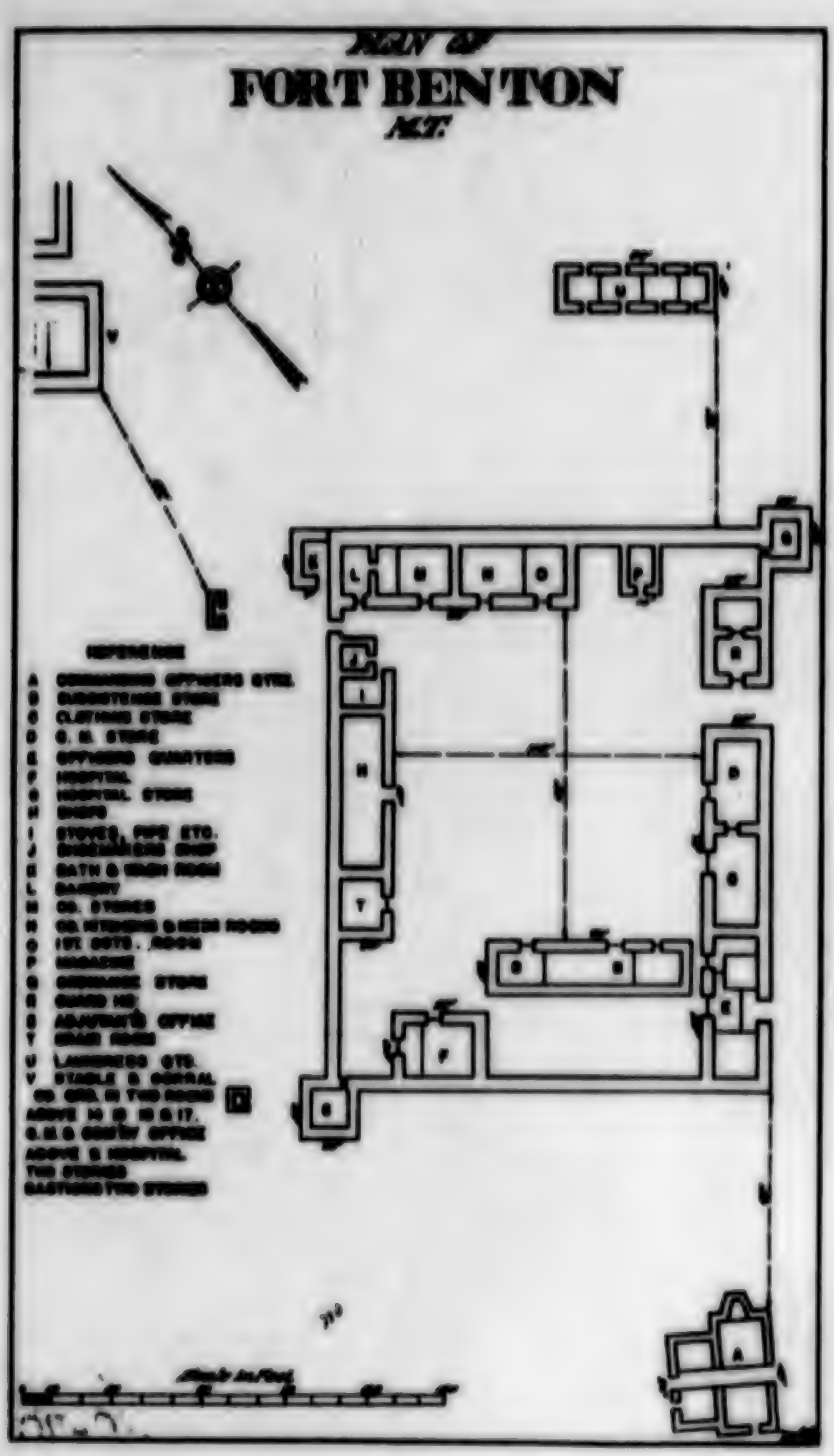
Maximum River Depth–10 Ft.

300 MHz. Antenna

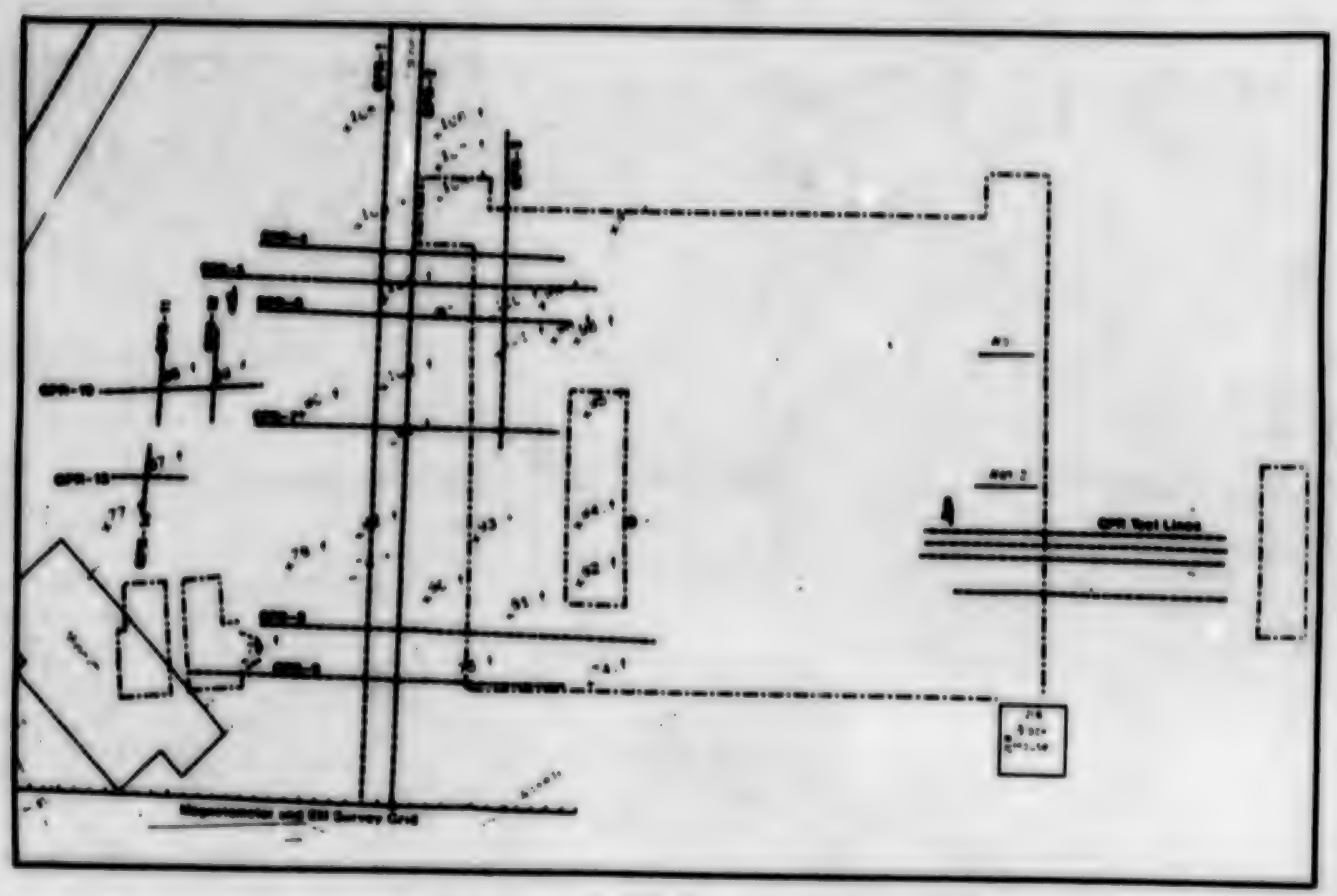
Horizontal Scale– 50 Ft.

MATERIAL	CONDUCTIVITY (mho/m)	RESISTIVITY (ohm/m)	DIELECTRIC CONSTANT	PULSE VELOCITY (Vm) in ns/ft
Air	0	0	1	1
Fresh Water	10^{-4} to 3×10^{-2}	10^{4} to 33.3	81	9
Sea Water	4	0.25	81	9
Sand (dry)	10^{-7} to 10^{-3}	10^{7} to 10^{3}	4-6	2-2.4
Sand (saturated)	10^{-4} to 10^{-2}	10^{4} to 100	30	5.5
Silt (saturated)	10^{-3} to 10^{-2}	10^{3} to 100	10	3.1
Clay (saturated)	10^{-1} to 1	10 to 1	8-12	2.8 - 3.3
Dry Sandy Coastal Land	2×10^{-3}	500	10	3.1
Marshy Forested Flat Land	8×10^{-3}	125	12	3.5
Rich Agricultural Land	10^{-2}	100	15	3.9
Pastoral Land Hilly, Forested	5×10^{-3}	200	13	3.6
Fresh Water Ice	10^{-4} to 10^{-2}	10^{4} to 100	4	2
Permafrost	10^{-5} to 10^{-2}	10^{5} to 100	4-8	2-2.9
Granite (dry)	10^{-8}	10^{8}	5	2.2
Limestone (dry)	10^{-9}	10^{9}	7-9	2.6
Dolomite			6.8-8	2.4-2.8
Quartz			4.3	2.1
Coal			4-5	2-2.2
Concrete			6.4	2.5
Asphalt			3-5	1.7-2.5
Sea Ice			4-12 (8)	2.2-3.3
PVC, Epoxy, Polyesters, Vinyls, Rubber			3	2

APPROXIMATE VHF ELECTROMAGNETIC PROPERTIES OF VARIOUS MATERIALS
Useful Ground Penetrating Radar Survey Information

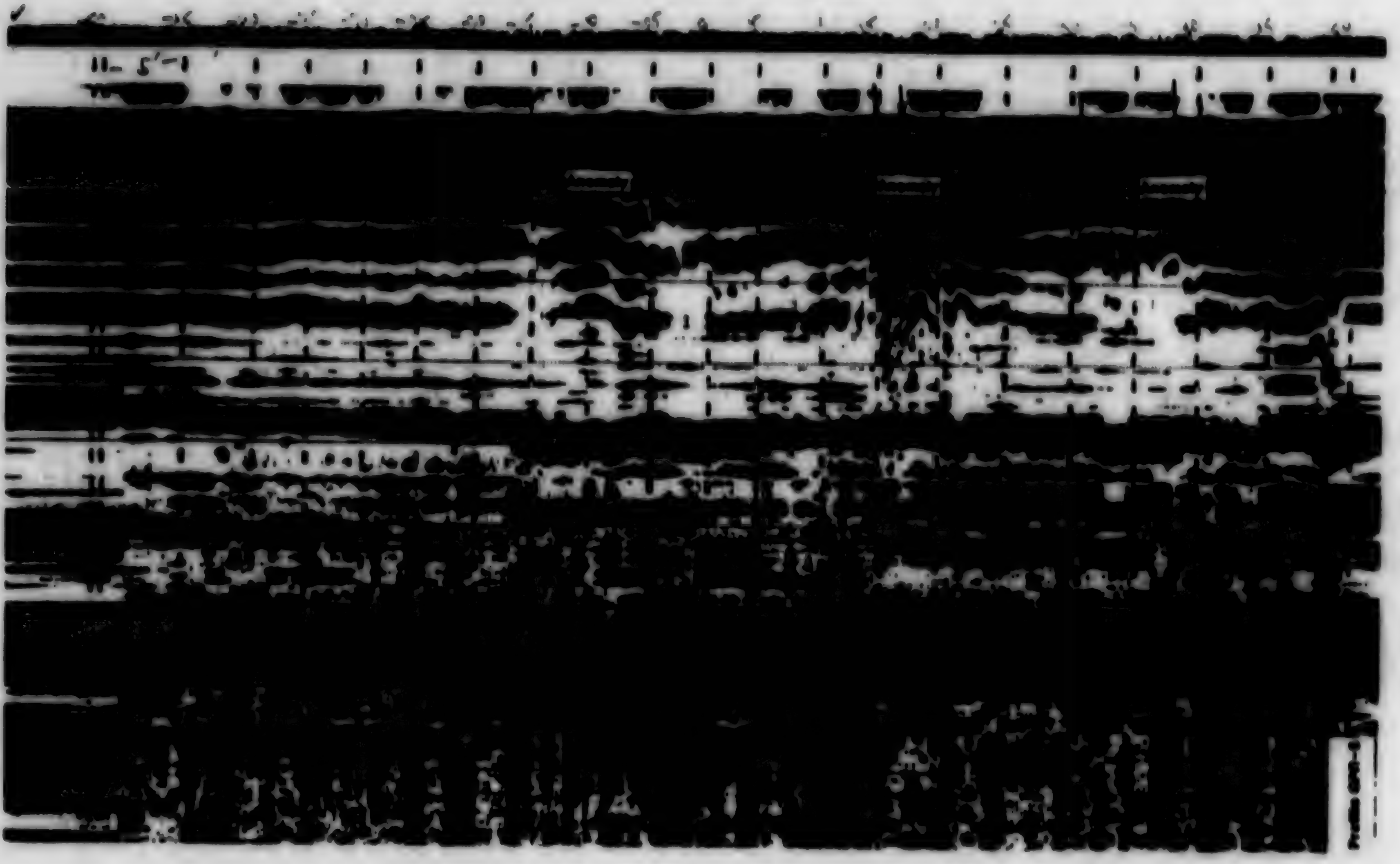


PLAN OF
FORT BENTON
M.T.

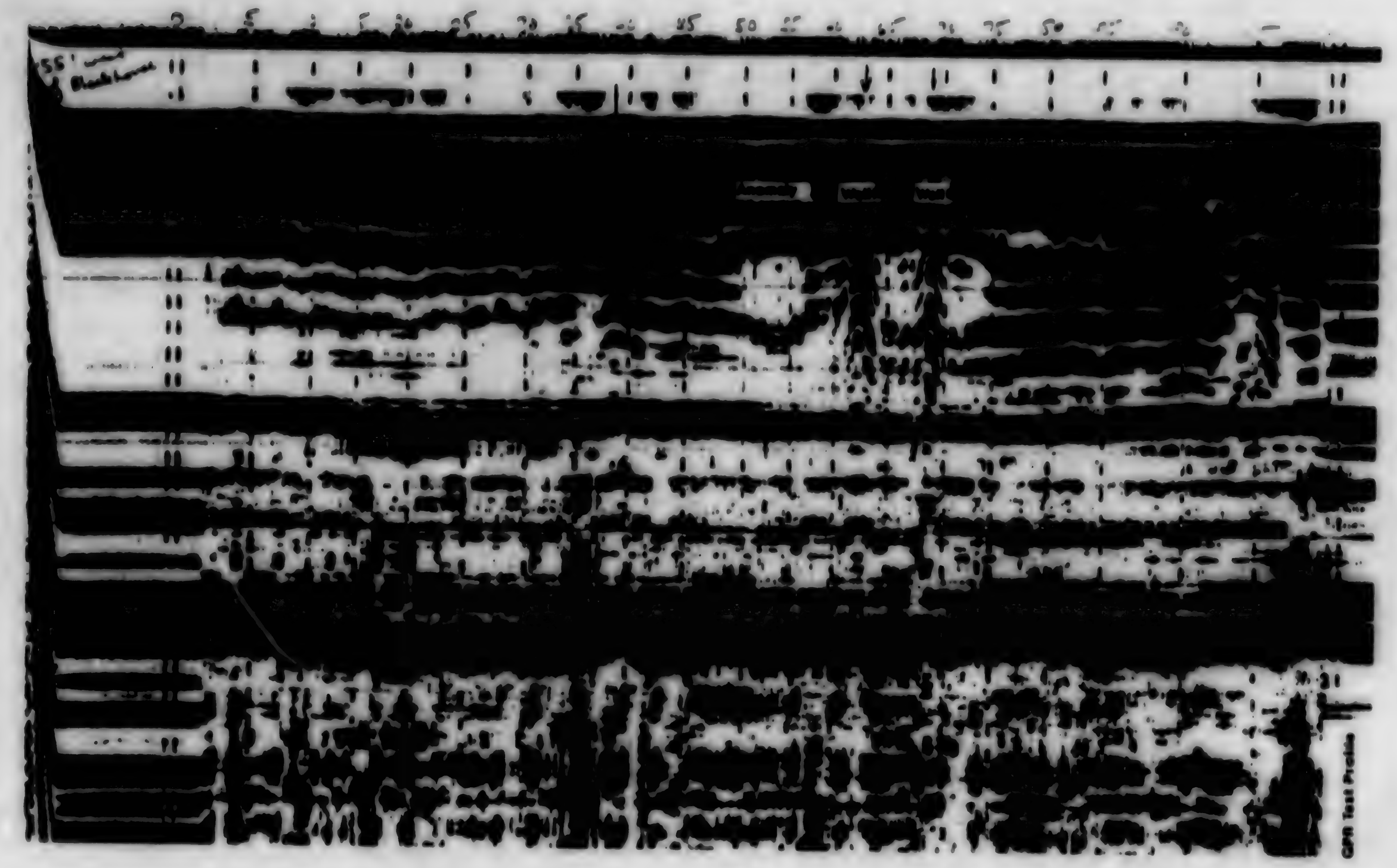


Fort Benton, Montana GPR Survey Line Map

Fort Benton, Montana GPR Profile



Fort Benton, Montana GPR Profile



Fort Laramie, Wyoming GPR Investigation of Fort William Site 1834

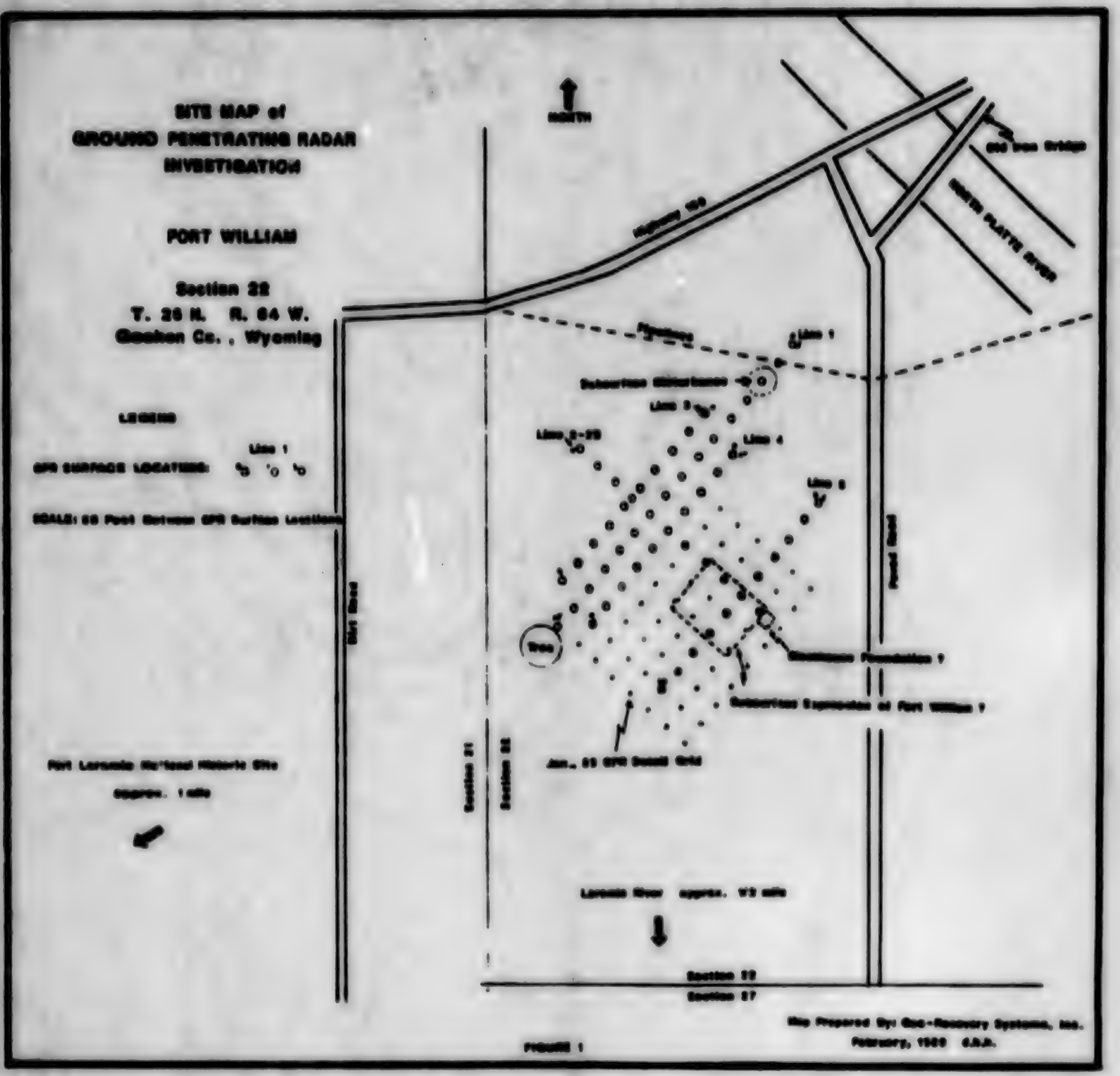
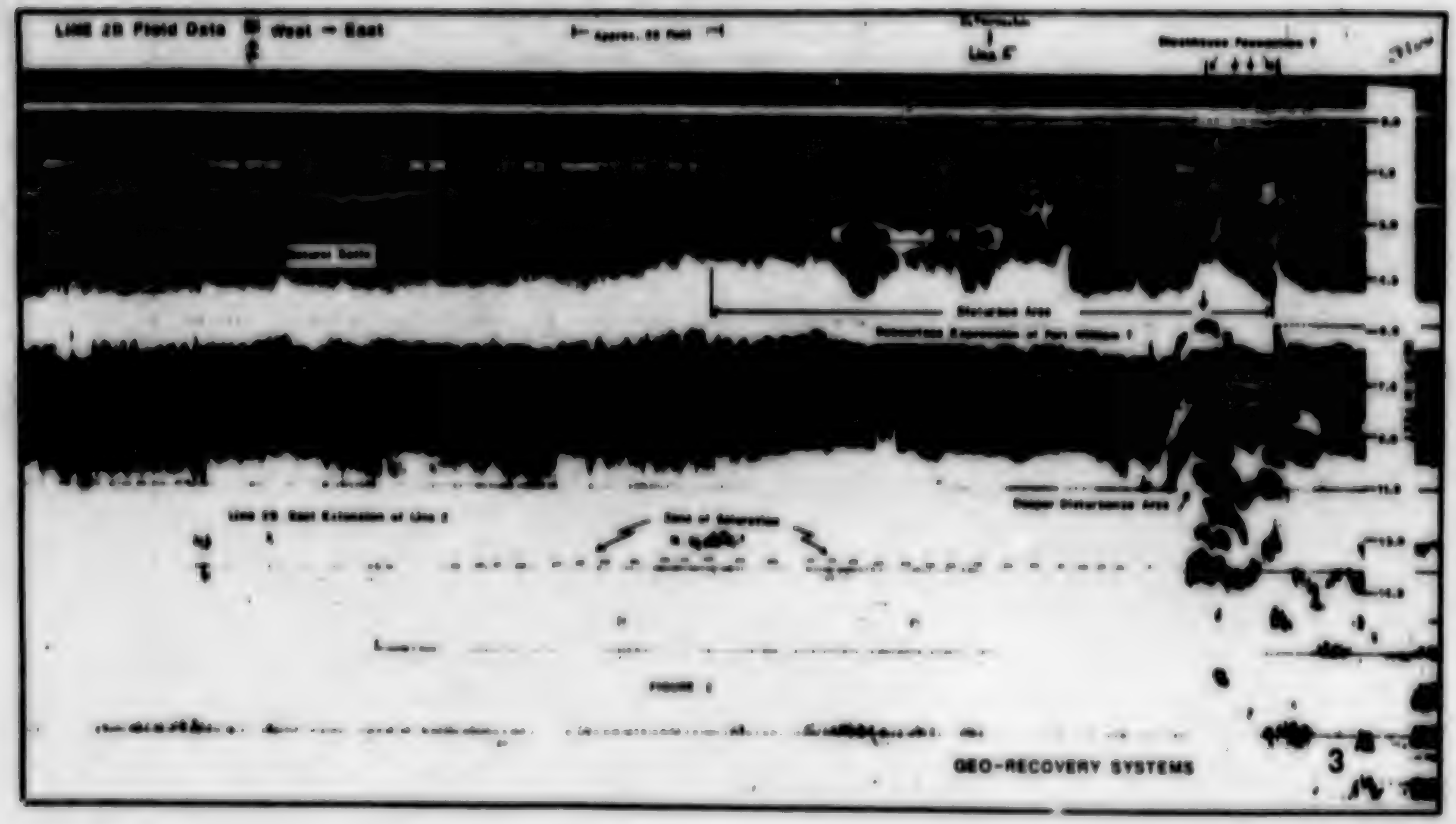
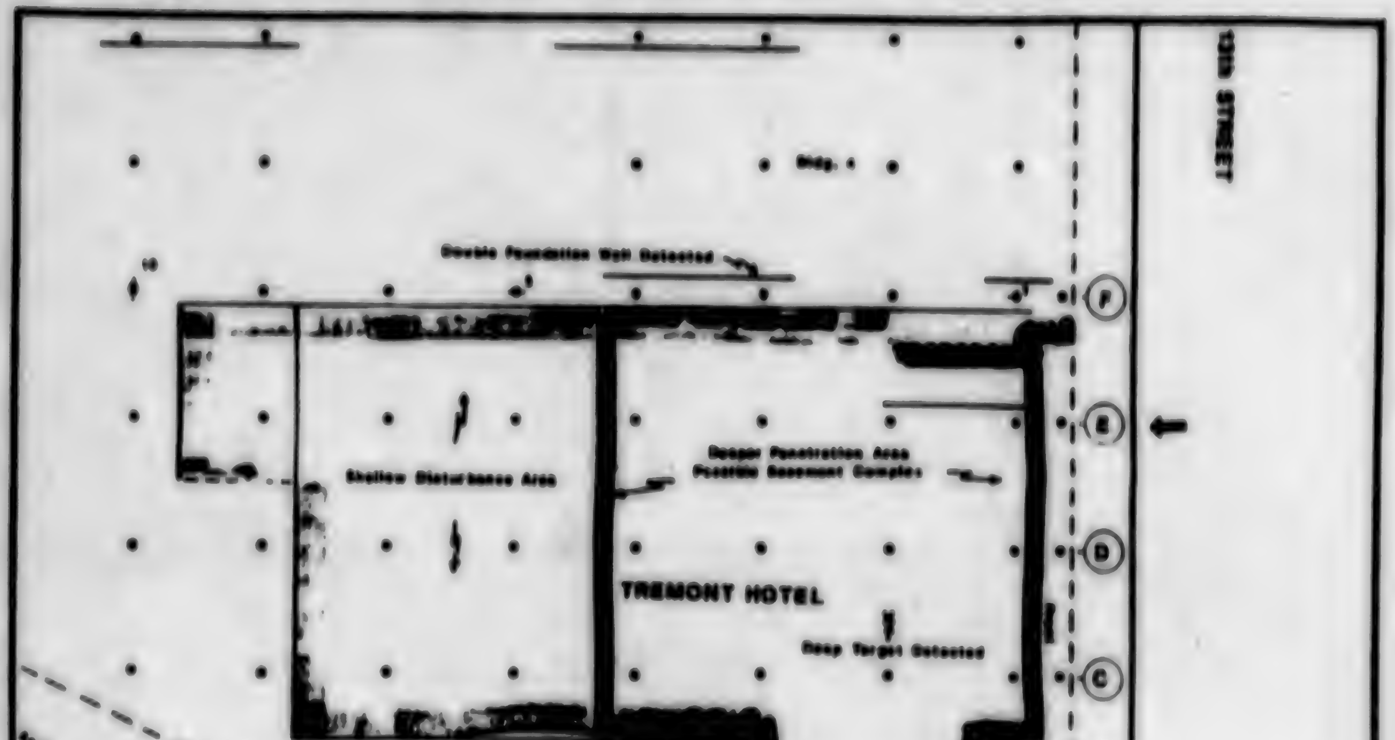


FIGURE 1

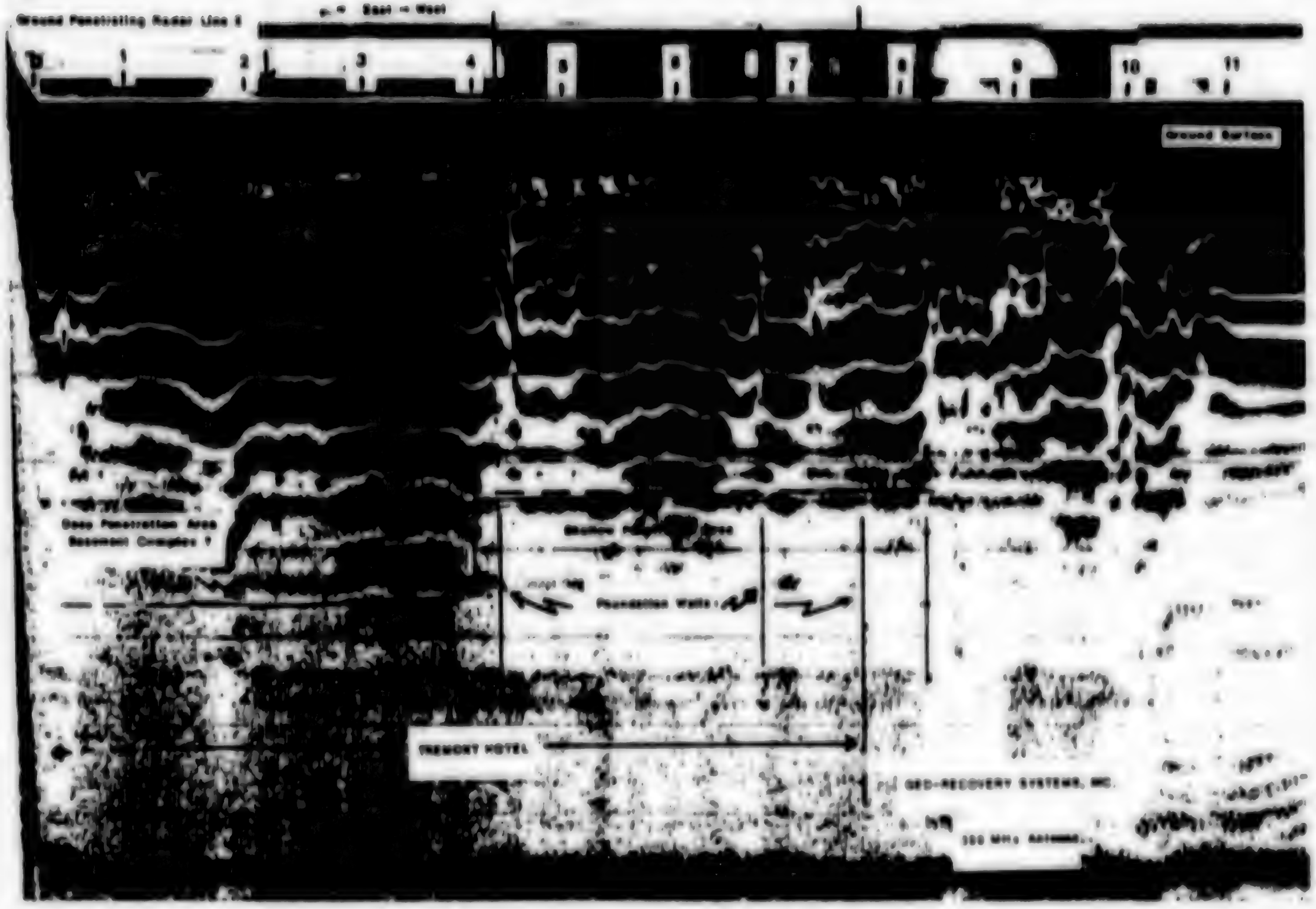
GPR Profile Fort William Site Line 2-2B



GPR Defined Structure Before Archaeological Excavation



Urban Archaeology GPR Profile Tremont Hotel

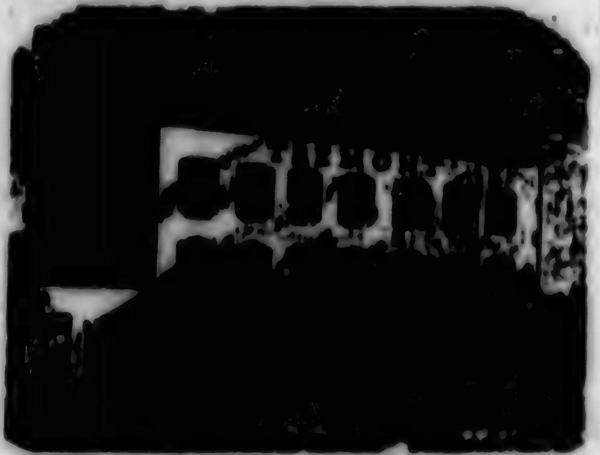


Typical Urban Archaeological Site

Denver digs

Speer project unearths historic brick Tremont hotel

By KEVIN FLYNN
Rocky Mountain News Staff Writer



Amid the dirt and grime of an excavation site in the shadow of Denver's 15th Street Viaduct, a glass bottle emerged with an embossed label that startled its discoverers.

"COCOCAINE," it read. "Boston."

But rather than stumbling across a pioneer drug den, the army of urban archeologists clearing a historic path for the new Speer Boulevard project downtown found something quite less sinister.

The bottle from the long-departed Tremont House hotel turned out to be a tonsorial tincture that were in vogue in the Wild West.

"We thought we found something exotic when we saw that bottle," said Barbara Norgren of the Colorado Historical Society. "Then we checked in a bottle book and learned it was a hair tonic."

While historians regret that this patch of land — now a parking lot for the Auraria Higher Education Center — will become part of the expanded Speer Boulevard roadbed, they are having a field day unearthing artifacts from what is said to be Denver's earliest brick building.

"We have no idea what's under there," Norgren said. But what has been learned since the "dig" started Dec. 10 is that the lower walls and slabs of the Tremont are amazingly intact under the surface of the soil.

And within those crumbling brick walls, a fascinating array of china, glass and other remains of the hotel has been untouched since the pioneer structure was demolished in 1913.

On Wednesday, the site will be opened to the media, although the general public won't be allowed in.

Workers with picks, shovels and trowels have been sifting through the dirt to recover as many artifacts as possible before the asphalt is laid down next year.

"We hope to learn a lot more about the Tremont through this," Norgren said. "It was one of the earliest hotels."

The two-story Tremont went up with bricks in 1860 — most of the cottonwoods already having been harvested for log structures in the Cherry Creek gold camp. At the time, the west bank of Cherry Creek was the town of Auraria. St. Charles, later called Denver City, was on the east bank. The two towns consolidated into Denver later that year.

From the balcony of the Tremont overlooking 15th and Blake streets, Colorado's first two territorial governors, William Gilpin and John Evans, gave their inaugural speeches.

After the demolition, no other building was constructed on the site, which became a storage yard for a nearby foundry. Because of that, the buried walls have been preserved remarkably intact.

"Nobody has ever done this before, deliberately set out to find the foundations of one of our historic buildings," Norgren said.

The historical society is involved because of federal rules governing the use of highway funds. Historic sites involved in highway projects have to be evaluated.

The Speer Boulevard project, a $27.6 million undertaking, is being administered by the Colorado Department of Highways for the city of Denver.

It involves replacement of the two viaducts — 14th and 15th streets — that make up Speer Boulevard's crossing of the Central Platte Valley. It is expected to help open the valley's former railyard areas — the area where Denver was born — to redevelopment.

Bandits raid ruins of Tremont House

By KEVIN FLYNN
Rocky Mountain News Staff Writer

Time bandits struck in the dark of night yesterday at one of Denver's oldest links with its past.

When archeological workers showed up yesterday to begin their final day of unearthing artifacts from the bowels of the old Tremont House hotel site in an Auraria campus parking lot, they found vandals had paid a nocturnal visit.

Chances are good, they say, that the late-night marauders weren't simply casual souls who stumbled onto the site. The glass

phalt parking lot near 15th and Blake streets make valuable additions to historic collections.

But the thieves likely were disappointed. Of the dozens of artifacts workers have found there over the past two weeks, only five were intact. The rest were in pieces — fine English china, bottles, goblets and other pieces encased in the rubble of one of Denver's first and finest frontier hostelries.

It is illegal to disturb or rob a historical site.

Richard Carrillo of La Junta, a historical archeologist hired by the state highway department to supervise the dig, said he doesn't know what the bandits might have

have been much intact.

A china plate whose edge had been exposed in earlier excavation was missing, chiseled out of the hardpacked sidewall of the 4-foot pit. But Carrillo is unsure it was an intact plate.

Carrillo planned yesterday to map the layers of dirt in the pit, which had been excavated as a flat surface for that purpose. But in the morning, highway department workers found the damage. The sidewall had been dug out, several cubic feet of dirt removed from three sides, and piled in the [illegible] of the pit.

Carrillo had planned to end the dig yesterday anyway, but not under these circumstances.

Coil Metal Detector

Model M-95 Valve and Box Locator

- Finds buried metal objects even in wet or mineralized ground.
- Enables you to detect or to ignore small items.
- Features solid-state circuitry, quick tuning, audible and visible indications.

The sensitive M-95 eliminates guesswork in pinpointing buried or paved-over pedestals, survey markers, manhole covers, and conduits. In fact, it can find items made of any metal, including iron, brass, copper, nickel, aluminum, steel, tin, and lead. It penetrates through soil, asphalt, or concrete.

Ground Effect Rejection

Because the Valve and Box Locator uses very low frequency waves (VLF), it can search through highly mineralized ground, black sand, wet ground, and foliage. This ground effect rejection even eliminates the false signals that might occur at each end of a swing or when the search head rises above the optimum distance from the ground.

Other Features

The unit features solid-state circuitry, rugged construction, and lightweight, compact design for optimum reliability and ease of operation. The standard ISOCON search head is electrostatically shielded, fully waterproof, and completely submersible. The shaft length is adjustable for the height and comfort of the operator. Battery testing is built into the unit.

Specifications

Head Operating Freq.	4.5 kHz
Sensitivity	0.2 mv RMS
Sensitivity Adj. Range	12:1
Outputs	Meter: 1 mA, 0-100 linear scale. Speaker 16Ω impedance. Audio Frequency: 480 Hz.
Power Supply	±9v, each consisting of 6-1.5v AA batteries (12 batteries total), or 2-9v NEDA 1604 batteries (with reduced battery life).
Dimensions	Search head: 8 in. diameter (203 mm). Shaft length: adjustable from 31 to 45 in. (787 to 1143 mm).

GISCO

Two Box Metal Detector

R-210 Pipe and Cable Locator

The new heavy duty locator allows operators a more efficient means for finding underground pipes, cables and conduits; tracing surveys; depth measurements; locating pipe bends and dead ends; and for eliminating damage and hazards before ditching and excavating. The locator is mounted in an "international orange" reinforced plastic case for high visibility and added safety. It operates inductively and conductively.

A dual filtering network rejects unwanted signals and interference giving better range of trace by clear identification of the generated signal. The innovative locator circuits provide greater sensitivity, stability and clarity of signal.

A meter with compression circuits has been designed for locator applications and provides easy identification of subtle underground shift of the trace object. Visual readings are more accurate and stable than with conventional meters. The R-210 signal frequency has been optimized for improved penetration of earth and more accurate vertical and horizontal pinpointing. There is also less carry-over from one utility to another to provide better focus on the desired trace object.

A tone interrupter prolongs average battery life from 200 to 500 hrs, depending on local temperature and usage. A plug-in format on "mother board" eliminates wire harnesses for long term dependability and low cost servicing.

There is no need of external earphones. A built-in loudspeaker overrides heavy traffic noises, allowing the operator more comfort and safety.

The pipe and cable locator has a bubble level for precise depth measurements, built-in battery testers, plug-in conductive plate and clamp, earphone jack, an automatic shut-off and provisions for future accessories without obsolescence. It is shipped complete and ready to operate with batteries.

Specifications

Transmitter	
Nominal Output Power.	
Inductive Mode.	100mW avg. (8.2V p-p across loop) (250% better than loop when using 46 Metroclamp*).
Conductive Mode.	125mW avg. (130V p-p across 2.7K ohms).
Output Frequency.	83kHz, modulated @ 389Hz.
Chopping Frequency.	4.5Hz.
Receiver	
Nominal Sensitivity at Loop (for 50% meter deflection):	
Lo Range.	4 microvolts p-p.
Med Range.	.44 microvolts p-p.
Hi Range.	.0044 microvolts p-p.
Sensitivity at AUX INPUT:	
Increase Over Loop.	20% with 4810 inductive probe. 375% with 43 Metroclamp.*

GISCO

---

*At 18" depth (46 cm).

Model ES-1225 12 Channel Signal Enhancement Exploration Seismograph

Features

- Signal enhancement — sums signals from repeated hammer blows. Allows operation in noisy conditions and to greater depths without explosives.
- Preview mode* — allows operator to decide if signal should be summed into memory. Prevents transient, high-level noise from ruining good data.
- Daylight-visible CRT monitor — displays data as it's being acquired so records can be optimized before printing "hard" copies.
- Electrosensitive plotter — produces permanent, annotated records on inexpensive, high-contrast, sunlight-proof paper.
- Improved reliability — advanced microprocessor design eliminates many failure-prone components and reduces the number of interconnections.

*Discretionary stack feature

Applications

- Depth-to-bedrock surveys
- Shearwave velocity measurements
- Weathering corrections surveys to correct for near surface distortion in reflection records
- Hazardous waste site surveys
- Rippability surveys to estimate excavation costs
- Mineral exploration including coal seam, placer gold, and gravel bed investigations
- Foundation site response studies
- Shallow reflection surveys to detail shallow layers
- Groundwater location and development surveys
- Rock mechanics measurements including foundation studies and mine safety evaluations
- Landslide, fault location, and geologic hazard evaluations

The Model ES-1225 Exploration Seismograph is intended to meet the needs of a variety of users. Civil engineers, engineering geologists, excavation contractors, university professors and students, mining engineers, and exploration geologists and geophysicists will find it to be a reliable instrument with uncomplicated operation and features ideal for their specific application. These features include 12-channels, signal enhancement, increased reliability, extreme portability, built-in CRT and plotter, filter, and ease of operation.

Specifications

Nonvolatile Memory.	When instrument is turned on, automatically restores last set of control settings used. Holds 12 sets of control settings, accessed with STORE and RECALL keys.
Memory Size.	1000 data points for each of 12 channels.
Sample Interval.	Selectable 25, 50, 100, 250, 500, or 1000 µs.
Record Duration.	Product of sample interval and total number of data points resulting in 25, 50, 100, 250, 500, or 1000 milliseconds.
Delay Time.	Postpones start of record. Adjustable from 0 to 1 second in .1 second increments.
Channel Freeze.	Protects data collected on specified channels from being erased or stacked with additional data.
Filter.	High-pass (low-cut), 2-pole filter is switch-selectable on or off from front panel. Attenuation is 12 db/octave, and filter frequency position is selectable by exchanging plug-in modules. Instrument comes with modules for 40 Hz cut off.
Amplifier Gain.	Twelve settings per channel, adjustable from 0 to 66 dB in 6 dB steps.
Trace Size.	Adjustable in values from 0 to 99.
Digital Input/Output.	Front panel RS-232 port allows data held in memory to be directly transferred to computers or other storage devices, or for recorded data to be played-back into the seismograph for display or additional stacking. Data format follows SEG standards. Data transfer rate is internal switch selectable at 110, 300, 600, 1200, 2400, 4800, or 9600 baud.
Noise Monitor.	Horizontal bouncing bar graphs for each channel. Accessible by pressing NOISE MONITOR key.
Digital Voltmeter.	Indicates battery voltage. Continuously displayed, flashes when voltage gets low.
Timing.	Crystal controlled 0.01% accuracy.
Record Initiation.	Via contact-closure, contact-open, saturated NPN transistor, positive or negative voltage pulse, or geophone signal.
Power Requirements.	12 volts, 3.5 amperes. Battery life is approximately 10 hours.

Instrument delivered with power pack, battery charger, power cables, 5 rls. recording paper, hammer switch and manual.

Optional Accessories

Vertical geophones, horizontal geophones, geophone spread cable, high voltage blaster. Please see ES-1 through ES-14 on page 56.

Additional literature available on request.

GISCO

Seismograph

Reflection Seismograph Model ES-2420

The ES-2420 is a sophisticated high-performance reflection seismograph using the latest design technologies to provide features that greatly contribute to the seismic acquisition task. In general, these features help to simplify system operation, increase the instrument's applications, and improve data quality. The ES-2420 is well-suited to all types of seismic applications, including petroleum exploration, Vertical Seismic Profiling (VSP Surveys), small-scale and high-resolution surveys, engineering site investigations, refraction surveys, and those using mechanical energy sources.

The system's design incorporates several unusual features: (1) a large semiconductor memory where data is temporarily stored and monitored before being written to tape; (2) a built-in summer so you can use mechanical energy sources, stacking repetitive signals to survey to great depths; (3) a built-in post acquisition processor providing enough computation power to make a considered evaluation of data while still in the field using digital filters, correlation, normal movement corrections, common offset gathers, and single velocity CDP stack; (4) 1/4-millisecond sampling on any number of channels so the system is appropriate for a wide variety of tasks; (5) menu-driven operation prompting the operator through selection of acquisition parameters and operation procedure; and (6) a built-in CRT displaying the data as it's being acquired.

The system also includes the basic functional characteristics of a reflection seismograph — instantaneous floating point amplifiers; precise amplitude resolution; appropriate alias, notch, and low-cut filters that are front-panel selectable over a wide range; and digital recording in SEG-D multiplex or demultiplex format.

The system is expandable from the basic two-unit package (which includes up to 28 channels, CRT display, tape controller, and tape recorder) to as many as 1080 channels.

Specifications

Acquisition Control Unit (ACU)	
Sample Interval.	Front-panel-selectable from ¼, ½, 1, 2, or 4 milliseconds.
Low-Cut Filter.	Settings selectable from 5 to 250 Hz in 5-Hz increments. Attenuation slope 18 db/octave.
Alias Filter.	Six frequencies, front-panel-selectable, linear phase 6-db frequencies: 45, 90, 180, 360, 720, and 1440 Hz. Attenuation 80 db at 128, 256, 512, 1024, 2048, and 4096 Hz.
Notch Filter.	Selectable 50- or 60-Hz notch filter, down 60 db at notch frequency.
Date and Time.	Internal clock with battery backup provides calendar date and 24-hour time of day, recorded on tape.
Acquisition Mode.	Data can be either stacked to system memory or written directly to tape.
Word Size.	Signal is digitized to a resolution of 15 bits with a 4-bit exponent representing 6-db gain steps.
Tape Format.	Data is recorded in either SEG-B multiplexed, SEG-D multiplexed, or SEG-D demultiplexed format, front-panel-selectable.
Maximum Stacks.	Any number of successive signals may be stacked into the memory.
Delay Start.	The start of acquisition may be delayed up to 9.999 seconds and varied in precise one-millisecond increments.
Memory Protect.	Any channels may be protected so that they will not erase, stack, or accept data from the geophones or tape recorder.
Test Functions.	Built-in self-test functions include: geophone resistance and leakage, pulse injection, staggered tone burst, sweep sine wave, fixed-frequency sine wave, memory test, tape verify against memory, and set to fixed gain.
Computation Functions.	Optional post-acquisition processing allows some analysis of data quality. Functions include: bandpass digital filters with selectable corner frequencies, cross-correlation with arbitrary reference channel, auto-correlation, mixing, common offset gathers, common depth-point stack, and more.
Maximum Record Length.	In stack to memory mode, depends on sample rate and memory length. ¼ ms = 4.096 seconds ½ ms = 8.192 seconds 1 ms = 16.384 seconds 2 ms = 32.768 seconds 4 ms = 65.536 seconds In direct-to-tape mode, the system can record indefinitely.
Acquisition Specifications.	Dynamic Range: >100 db Crossfeed Isolation: 80 db Distortion: 0.05% Noise: 0.25 microvolts rms
Plotter.	Digital plotter plots data on 8.5-inch-wide paper. Plots in variable area or wiggle trace as determined by CRT display. Annotates plot with header information, time lines, and recording parameters. Has minimal controls since plotting, including the setting of scale factors and time period to be plotted, is controlled by the ACU. Time required to plot depends on scale factor and selection of time interval plotted.
Digital Tape Recorder.	Portable tape recorder available with system. 7½-inch reel with 1200 ft of tape. Recording and playback speed: 37½ ips. In direct-to-tape mode the recorder can support an acquisition rate of 2 ms for 28 channels or 1 ms for 14 channels in continuous recording.

Detailed technical specifications available on request.

GISCO

Acoustic Emission Monitor Model AEM-86

Features

- Rugged lightweight field unit.
- Easy-to-use controls are set without oscilloscope.
- Battery operated.
- Audible output for headphones or user supplied tape recorder (not included).
- Digital display and permanent dual-trace strip chart record of both Total Counts (TOTAL) and Counts Per Minute (CPM).
- Analog outputs of all signals for external recorders.
- Calibrated amplifier gains and filter settings
- Battery condition indicator. Monitor provides automatic shutdown to protect battery from over-discharge
- Transducers may be either pressure or acceleration sensitive. Remote preamplifier option is available for noisy environments or for use over long wires.

Acoustic Emission Monitor

Acoustic emissions are impulsive subaudible sound waves caused by the release of stored elastic strain energy in stressed materials. These sounds may be generated by instabilities in earthen dams and slopes, behind retaining walls, beneath footings and in underground openings, mines, and quarries. Although normally small in amplitude, they can be monitored by sensitive detectors which convert the waves into electrical signals. When suitably amplified, filtered, and quantified, they are used to give an indication of stress conditions and stability in the material being monitored.

The Acoustic Emission Monitor is a portable, easy-to-use, modular, field instrument designed to simplify the recording of acoustic emissions in natural environments. Small size and low power consumption make this unit particularly well suited for remote or unattended installations.

The basic single channel unit consists of a sensitive receiver element with an instrument case containing signal processing electronics and a dual-trace strip chart recorder. While observing the display, the operator selects the proper gain, bandwidth, and trigger level by setting calibrated switches. He may simultaneously listen on headphones and observe the signals on a portable oscilloscope (not supplied) via outputs on the front panel. Total counts and the average count rate are computed and recorded. They are also output to BNC connectors. Both quantities are displayed by a two-digit LED readout. With slight modification, acoustic event counting is also possible. A permanent record of raw data can be made by recording the audio or test outputs on an external tape recorder.

Detection of Acoustic Emissions

Acoustic emissions are detected by a transducer placed on a wave guide or lowered to the desired level in a borehole. The acoustic emissions are then converted by the transducer into an electrical pulse which is amplified and filtered. All frequencies outside of the 500 Hz to 5,000 Hz range are generally considered to be extraneous noises caused by wind, operation of nearby equipment, airplanes, etc. Emissions are counted electronically, and the counts are recorded on a strip-type recorder. The slope of the line appearing on the chart represents the number of counts per unit time. Regarding the significance of acoustic emission rates, Koerner, Lord, and McCabe (1978) report the following:

0-10 counts/minute — condition stable
10-100 counts/minute — moderately stable
100-500 counts/minute — unstable conditions
500+ — state of failure

As more field data become available, more detailed quantitative assessments of acoustic emissions can be made.

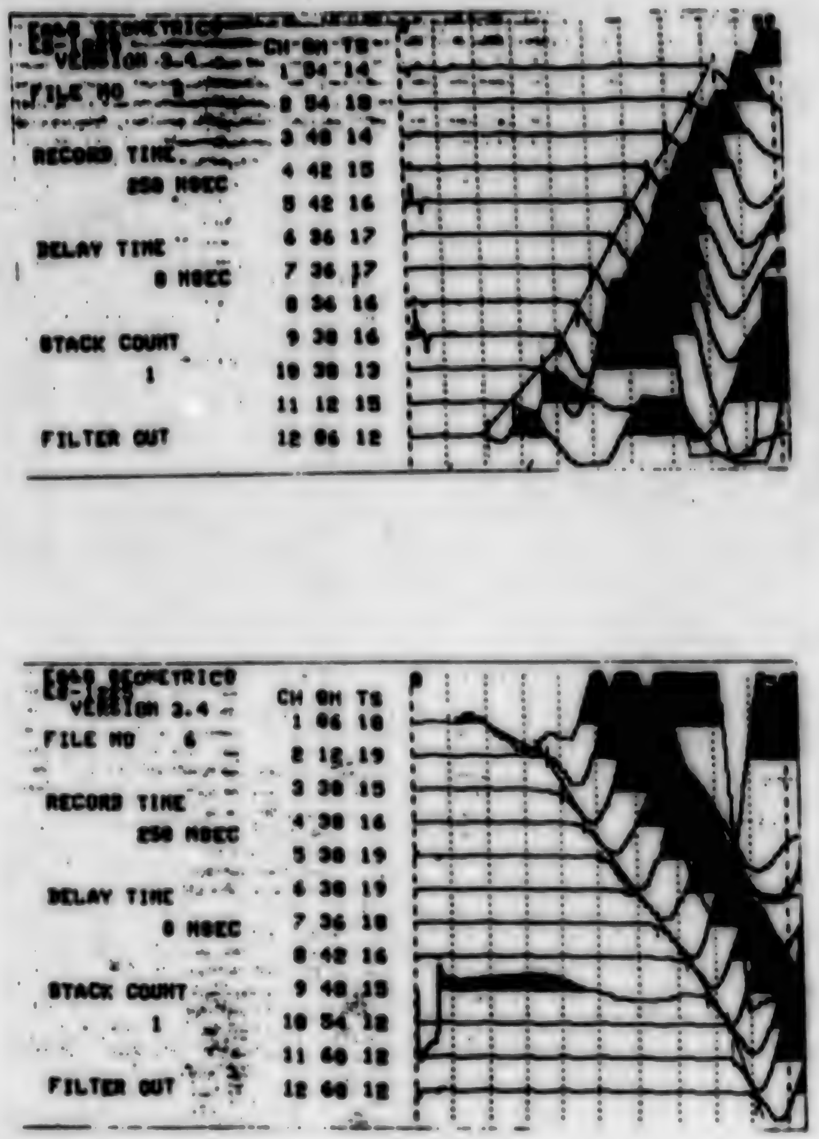
Acoustic emissions are generally produced at a low amplitude. For that particular amplitude and time, the frequencies are variable. Most workers focus their attention on the 500 Hz to 5,000 Hz band, but it should be recognized that frequencies within a band of less than 500 Hz or as high as several megahertz can be produced. The area to be tested should undergo a preliminary geologic assessment. A determination of background noise for the entire site should be made prior to monitoring acoustic emissions.

Specifications

Specifications apply to the single channel basic unit with a pressure transducer, one battery and a dual channel recorder

Gain	20dB preamplifier followed by 74dB of gain adjustable from 1 to 5,000 in a 1, 2, 5 sequence
Bandwidth	300 Hz to 50 kHz
Filters	2-pole state variable active linear phase Bessel selectable in a 1, 2, 5 sequence High pass — 20 Hz to 20 kHz Low pass — 500 Hz to 50 kHz
Noise	30 nv/(Hz)½ amplifier wideband input noise density, 56 nv/(Hz)½ equivalent sensor wideband noise density
Display	2 digit LED, switch-selectable to show either TOTAL or CPM. Off position reduces power consumption.
Scale	100, 1,000 and 10,000 TOTAL or CPM full scale
Time Base	Internal crystal. Drift rate less than ±10 sec/day
Outputs:	
Amplifier	±10v full scale from linear filter amplifier
Audio	Low impedance output for headphones or tape recorder
Total	+10v full scale proportional to total counts
CPM	+10v full scale from linear filter amplifier
Recorder	Dual-trace strip chart for TOTAL and CPM data with 15-day paper supply and take-up reel
Power	12-volt rechargeable internal battery or external (car) battery
Operating Time	48 hrs with internal battery. Up to 192 hrs with optional internal battery packs. Car battery lasts 30 days (with LED display off)
Sensors	Hydrophones or accelerometer

Seismic Refraction Records

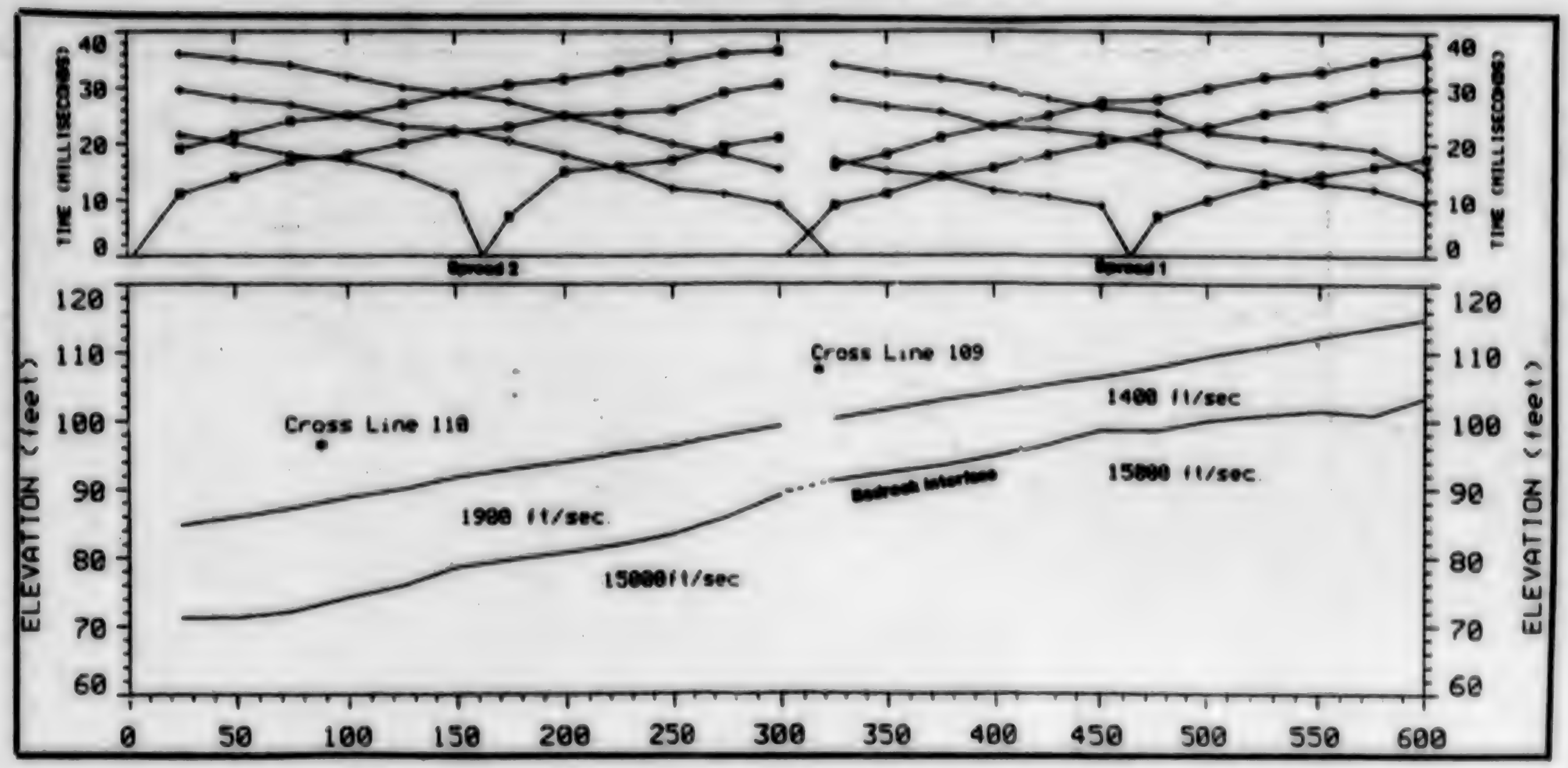


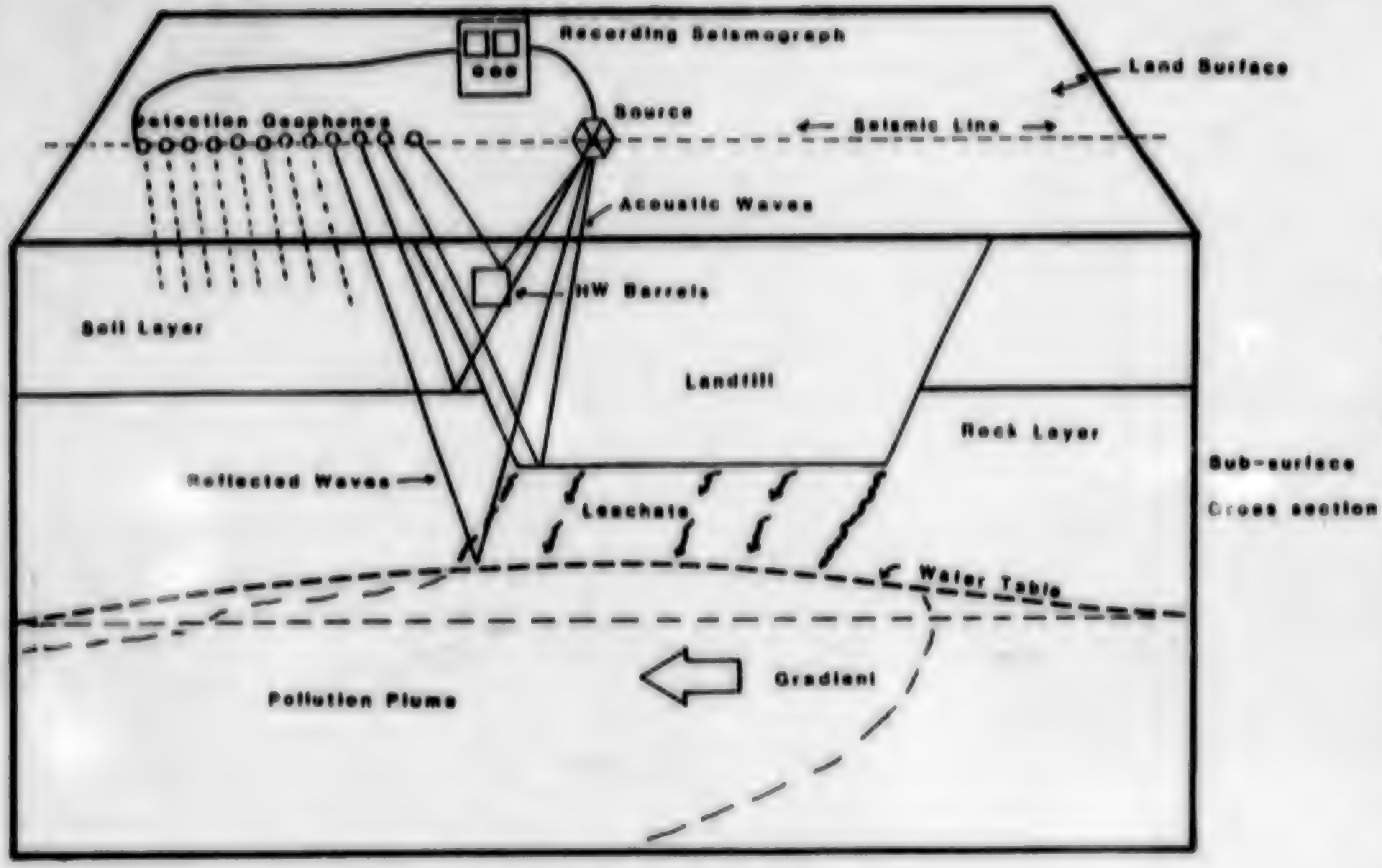
```
EG&G GEOMETRICS
ES-1225
  VERSION 3.4         CH GN TS
                       1 54 14
FILE NO    3           2 54 18
                       3 48 14
 RECORD TIME           4 42 15
        250 MSEC       5 42 16
                       6 36 17
 DELAY TIME            7 36 17
          0 MSEC       8 36 16
                       9 30 16
 STACK COUNT          10 30 13
          1           11 12 15
 FILTER OUT           12 06 12
```

```
EG&G GEOMETRICS
ES-1225
  VERSION 3.4         CH GN TS
                       1 06 18
 FILE NO    6          2 12 19
                       3 30 15
 RECORD TIME           4 30 16
        250 MSEC       5 30 19
                       6 30 19
 DELAY TIME            7 36 18
          0 MSEC       8 42 16
                       9 48 15
 STACK COUNT          10 54 12
          1           11 60 12
 FILTER OUT           12 60 12
```

Seismic Refraction Data Example

Seismic Refraction Data

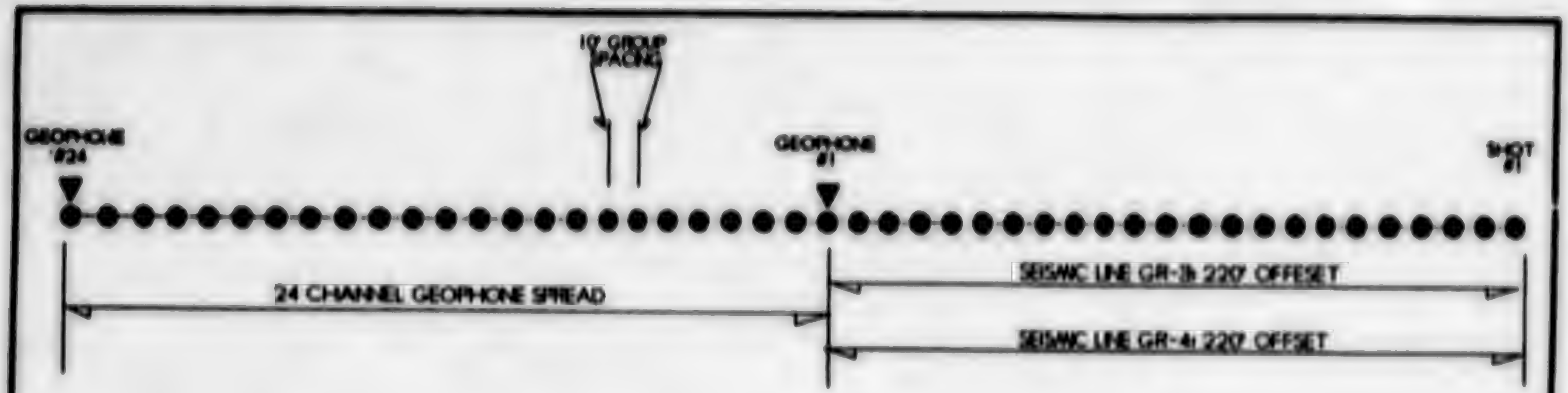




Schematic Field Layout of Seismographic Survey

Over a Hazardous Waste / Landfill Site

DHH/87

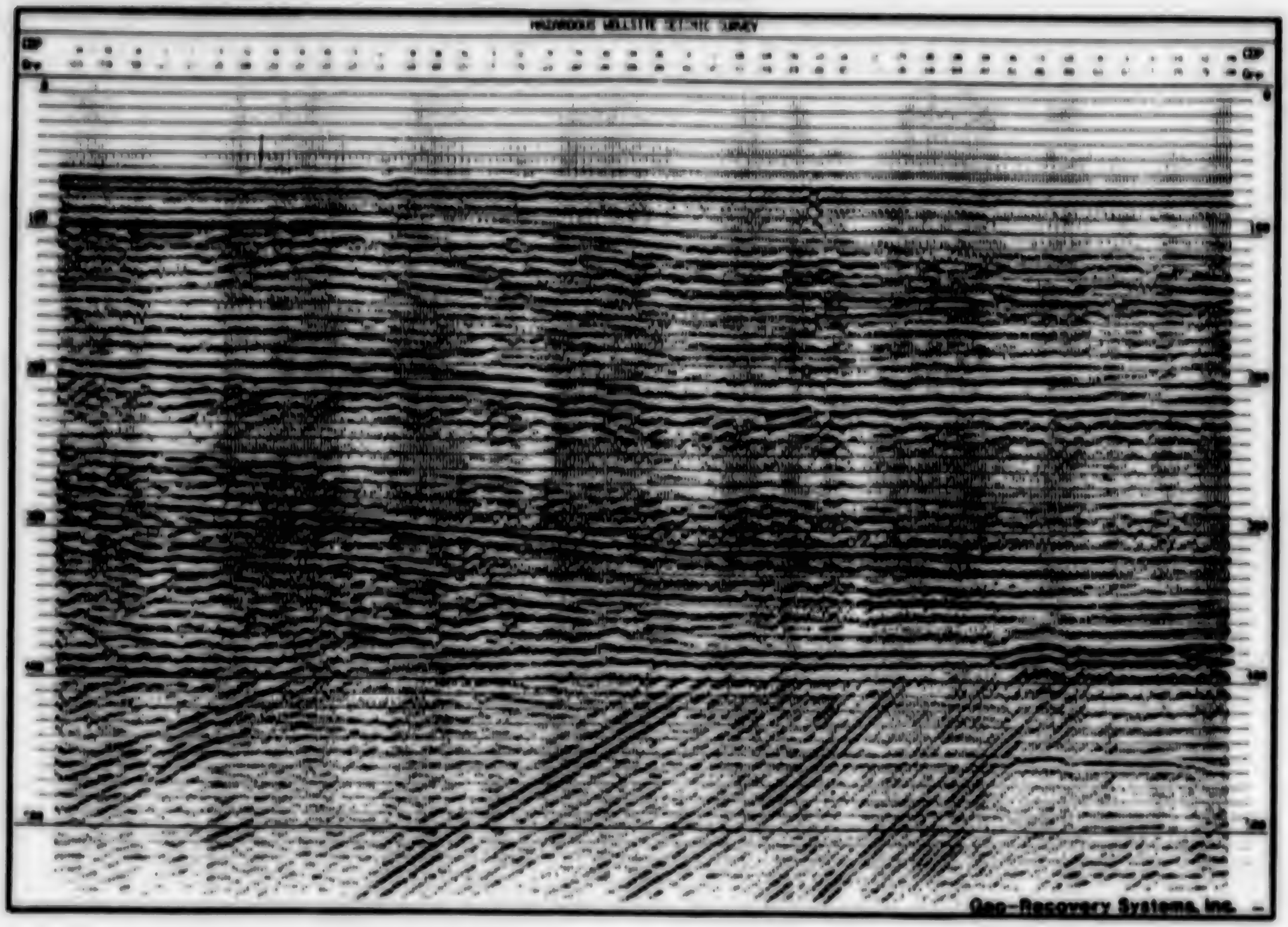

10' GROUP SPACING
GEOPHONE #24
GEOPHONE #1
SHOT #1
24 CHANNEL GEOPHONE SPREAD
SEISMIC LINE GR-3: 220' OFFSET
SEISMIC LINE GR-4: 220' OFFSET

Seismic Line GR-3: 1200 Ft. North of Leyden Road

Seismic Line GR-4: Well 21 to Leyden Road

SEISMIC REFLECTION SURVEY GEOMETRY

Seismic Reflection Data



Geo-Recovery Systems, Inc.

PROJECT________________
LINE NO.________________
DIRECTION_______________
GEOPHONES PER TRACE____
GEOPHONE ARRAY__________
GROUP INTERVAL__________
GEOPHONE FREQUENCY_____

SHOTPOINT INTERVAL______

TAPE NO.____________________
TAPE HEADER__________________
RECORD LENGTH________________
SAMPLE RATE_____ FORMAT_____
START TIME_____END TIME_____
DATE__________PAGE___OF_____

FILE #	SPREAD LOCATION	SHOT #	SHOT LOC.	SHOT OFF.	SHOT DEPTH	CHARGE SIZE	STACK	FILTERS HI/LO	GAIN	PARITY ERRORS	REMARKS

SHEET ___ OF ___

SEISMIC REFRACTION-DATA SHEET

FEATURE ______________________ PROJECT ______________________ STATE ____________
LINE NO. ______ SPREAD NO. ______ LOCATION ______________________ SURVEY DIRECTION ________
EQUIPMENT ______________________ OPERATOR ______________________ DATE ____________

GEOPHONE NUMBER												
DISTANCE FEET IN LINE												
DISTANCE FEET TRANS												
ELEVATION FEET												
NORMAL TIME MILLISEC.												
CENTER TIME MILLISEC.												
REVERSE TIME MILLISEC.												
NOR. OFFSET TIME MILLISEC.												
REV OFFSET TIME MILLISEC.												
GEOPHONE NUMBER												
DISTANCE FEET IN LINE												
DISTANCE FEET TRANS												
ELEVATION FEET												
NORMAL TIME MILLISEC.												
CENTER TIME MILLISEC.												
REVERSE TIME MILLISEC.												
NOR. OFFSET TIME MILLISEC.												
REV OFFSET TIME MILLISEC.												

NORMAL SHOT POINT

SHOT POINT ________ COORDS. N. ________________ E. ________________ ELEV. ________
DISTANCE IN LINE _____ DISTANCE TRANSVERSE _____ DEPTH _____ SOURCE ______________

CENTER SHOT POINT

SHOT POINT ________ COORDS. N. ________________ E. ________________ ELEV. ________
DISTANCE IN LINE _____ DISTANCE TRANSVERSE _____ DEPTH _____ SOURCE ______________

REVERSE SHOT POINT

SHOT POINT ________ COORDS. N. ________________ E. ________________ ELEV. ________
DISTANCE IN LINE _____ DISTANCE TRANSVERSE _____ DEPTH _____ SOURCE ______________

NORMAL OFFSET SHOT POINT

SHOT POINT ________ COORDS. N. ________________ E. ________________ ELEV. ________
DISTANCE IN LINE _____ DISTANCE TRANSVERSE _____ DEPTH _____ SOURCE ______________

REVERSE OFFSET SHOT POINT

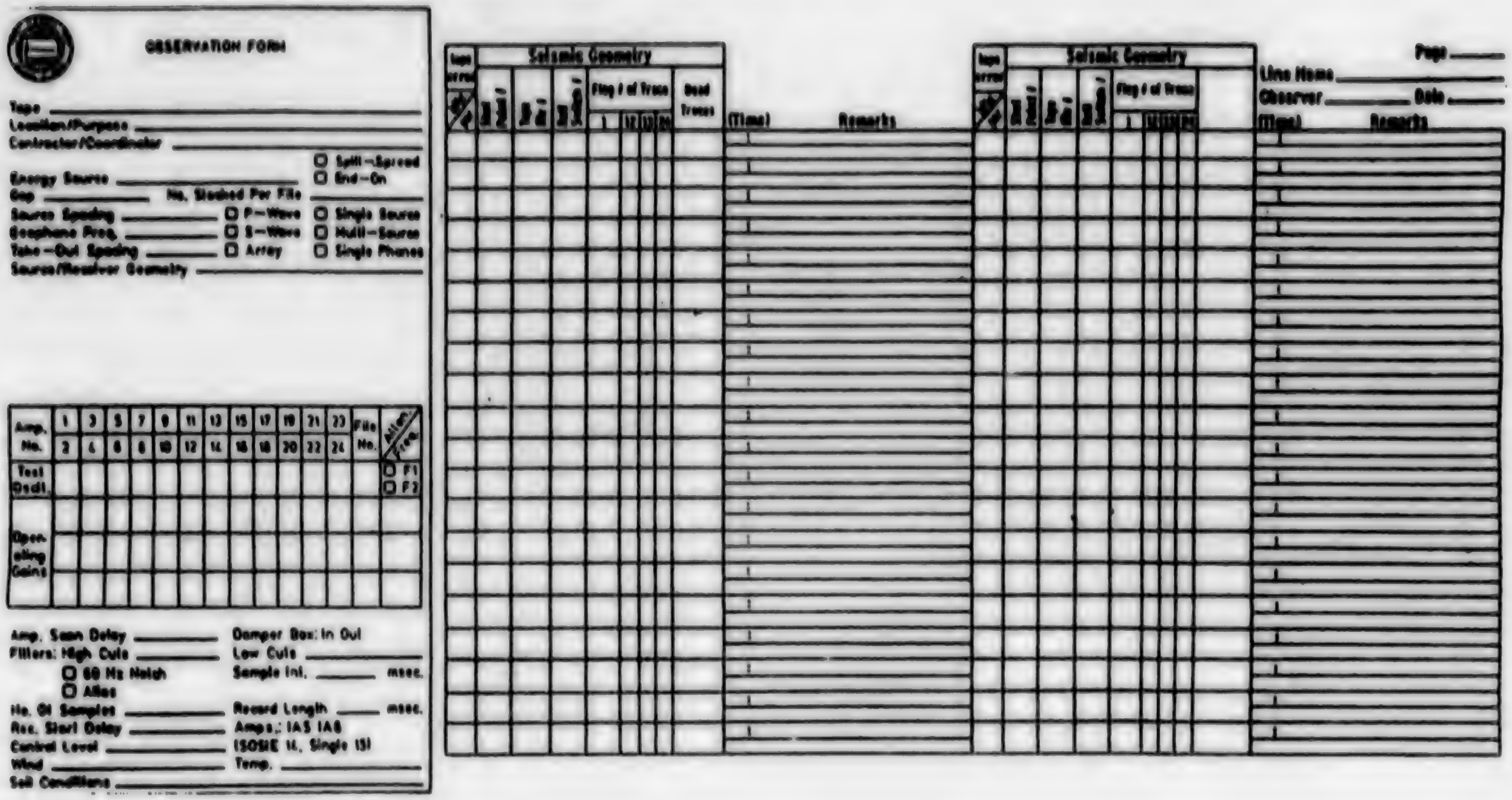
SHOT POINT ________ COORDS. N. ________________ E ________________ ELEV. ________
DISTANCE IN LINE _____ DISTANCE TRANSVERSE _____ DEPTH _____ SOURCE ______________

COMMENTS:

Davenport & Hadley 1986

BLANK
PAGE

Seismic Reflection Survey Data Form



OBSERVATION FORM

Tape ____________________
Location/Purpose ____________________
Contractor/Coordinator ____________________
☐ Split-Spread
Energy Source ____________________ ☐ End-On
Gap __________ No. Stacked Per File __________
Source Spacing __________ ☐ P-Wave ☐ Single Source
Geophone Freq. __________ ☐ S-Wave ☐ Multi-Source
Take-Out Spacing __________ ☐ Array ☐ Single Phones
Source/Receiver Geometry ____________________

Amp. No.	1 2	3 4	5 6	7 8	9 10	11 12	13 14	15 16	17 18	19 20	21 22	23 24	File No.	Atten./Freq.
Test Oscil.														☐ F1 ☐ F2
Operating Gains														

Amp. Scan Delay __________ Damper Box: In Out
Filters: High Cuts __________ Low Cuts __________
☐ 60 Hz Notch Sample Int. ______ msec.
☐ Alias
No. Of Samples __________ Record Length ______ msec.
Rec. Start Delay __________ Amps.: IAS IA8
Control Level __________ (ISOSIE 16, Single 15)
Wind __________ Temp. __________
Soil Conditions ____________________

Tape error	Seismic Geometry								(Time)	Remarks
	[illegible]	[illegible]	[illegible]	Flag # of Trace				Dead Traces		
				1	12	13	24			

Page ______
Line Name ____________________
Observer __________ Date ______

Tape error	Seismic Geometry								(Time)	Remarks
	[illegible]	[illegible]	[illegible]	Flag # of Trace						
				1	12	13	24			

Side Scan Sonar

Side-Scan Sonar 500SS

The WESMAR 500SS Side-Scan Sonar system can locate and identify underwater objects, explore and map seabed terrain, plan informed diving, and paint a permanent record of underwater topography on 8" chart paper. Sixteen shades of grey indicates target density with dark grey representing denser objects.

The Side Scan uses sonar transducers to sweep the sea bottom with two fan-shaped acoustic beams transmitted at right angles from the submerged tow fish. The beam is 1.5 degrees in the horizontal plane and 35 degrees in the vertical plane.

The twin fan-shaped beams are reflected by topographical features and submerged objects, on or near the sea bottom. This reflected acoustic energy is detected by the tow fish and charted on the shipboard chart recorder for an easily interpreted, continuous and permanent "picture" of the sea bottom.

The WESMAR Side-Scan system features a lightweight (under 15 lbs.), portable tow fish that requires no winch for handling. The recorder can print left and right channels simultaneously or, for a larger picture, print one channel across the full 8 inches of paper.

Seven ranges from 100 to 1600 feet and five paper speeds help produce the most informative picture to match the particular tow speed, depth and desired targets. Independent left and right near-far gain controls highlight targets at all ranges. A push-button "Event" marker lets the operator mark points of interest for later reference. Transmitter pulse width is adjustable for maximum resolution.

System Description

The 500SS Side Scan system includes tow fish, downrigger, tow bar, recorder, 200 ft. (61 m) of tow cable, chart paper, power cord, owner's manual.

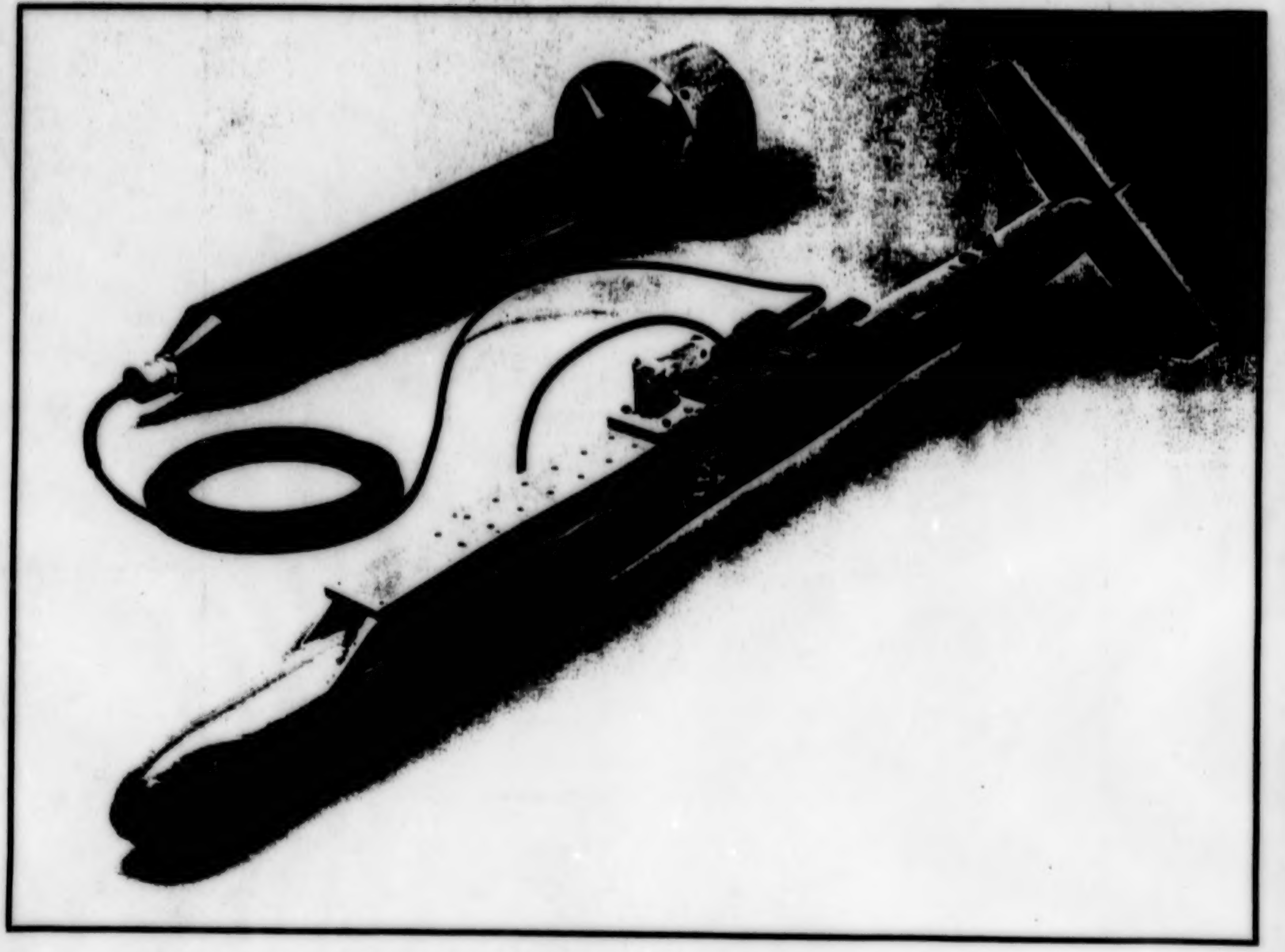
Specifications

Recorder	
Signal Resolution.	4 bits, 16 shades, 64 marking points per inch.
Recording Paper.	Dry, electrosensitive 8-inch paper.
Ranges (feet).	100, 150, 250, 400, 600, 1000, 1600.
Ranges (meters).	30, 45, 75, 120, 180, 300, 480.
Display.	Left and right, left or right.
Chart Advance.	Selectable, 5 speeds, internal clock.
Power.	500SS, 36 watts, 12 VDC.
Console Dimensions.	16.5 in x 14.5 in. x 7 in. (419 mm x 368 mm x 178 mm).
Tow Fish	
Frequency.	107 Khz.
Beam Width.	Horizontal, 1.5°, vertical, 35°
Tilt.	+90° to -90°, manual adjustment.
Maximum Depth Range.	610 ft. (186 m) with standard downrigger @ 1.5 knots, with 1000 ft. (305 m) cable
Transmit Pulse Width.	500SS 100µ sec. to 500µ sec.
Tow Fish Weight.	500SS 13.3 lbs. (5.89 kg).
Downrigger Weight.	8 lbs., 4 oz. (3.75 g)
Tow Fish Dimensions (overall with fins).	Length, 28.5 in. (724 mm); width, 19.5 in. (495 mm); height, 17 in. (432 mm)
Tow Fish Dimensions (body).	Length, 27 in. (686 mm); width, 5 in. (127 mm); height, 1.75 in. (44 mm).
Tow Cable	RG122/U coaxial cable around 3/32 in. stainless steel member, D.P.R. blocking, black polyurethane jacket, 1000 lb. pull strength.

Please write for complete Specification Sheet.

GISCO

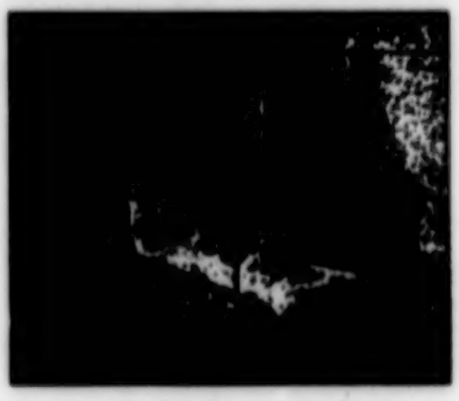
EG&G Magscan



Combined Magnetometer and Side Scan Sonar

Side Scan Sonar Examples

Side scan is often used to locate and examine shipwrecks. This Klein 500 kHz record shows the Vineyard Sound Lightship, sunk in 1944 in 25 meters of water off the coast of Massachusetts.



Klein 100 kHz record of schooner Hamilton, sunk in Lake Erie during War of 1812.

Side scan sonar is often used to locate the sites of airplanes that have crashed in the water. This record shows a Klein 100 kHz record of a Wellington bomber in Loch Ness

Printed on Recycled Paper

☆U.S. GOVERNMENT PRINTING OFFICE: 1990-775-195/85017

END

6 - 17 - 94